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Ship Navigation Simulation Study, Houston-Galveston Navigation Channels, Texas

Report 4 Houston Ship Channel - Gulf Intracoastal Waterway Intersection

by Dennis W. Webb

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Prepared for U.S. Army Engineer District, Galveston

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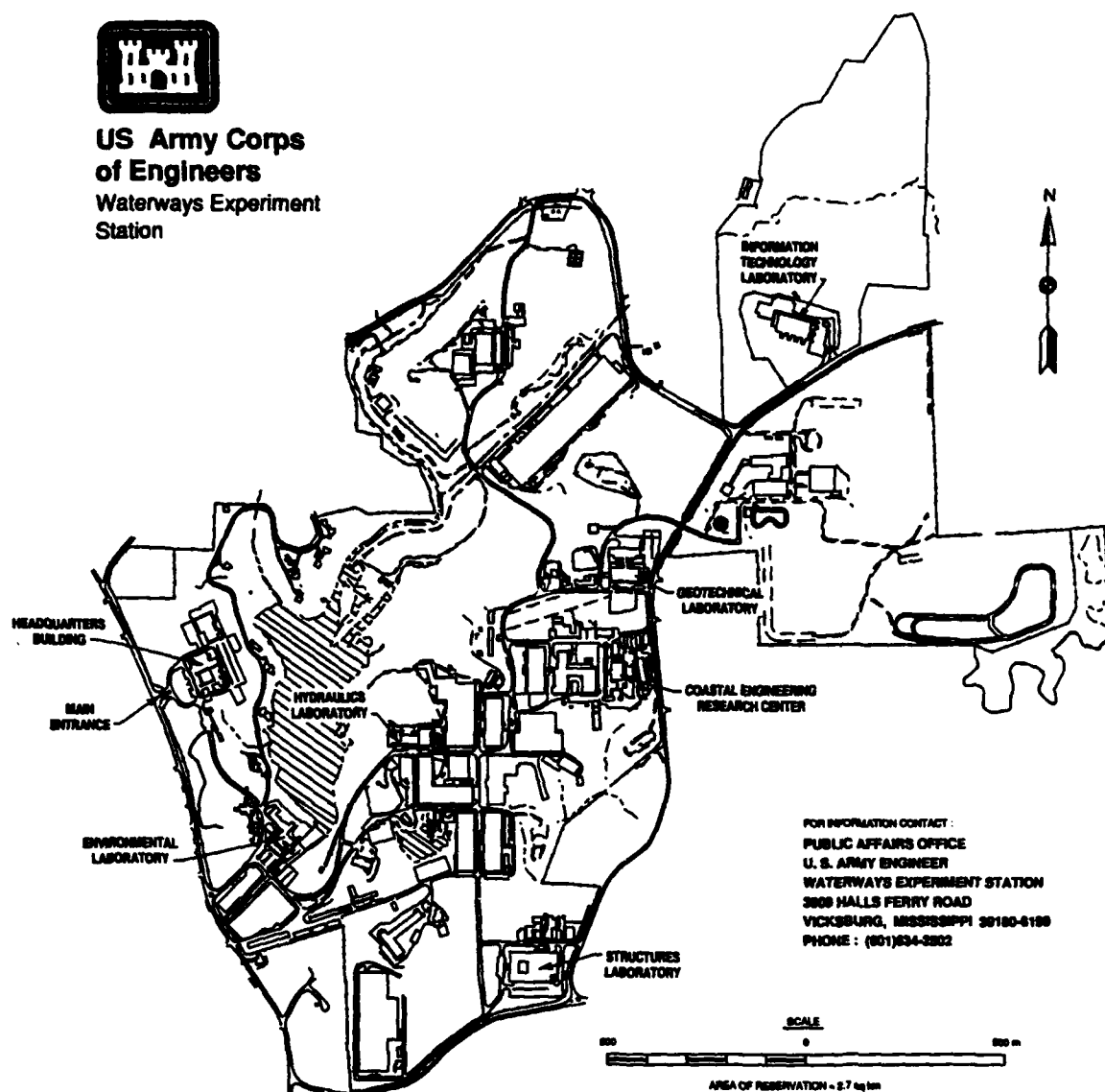
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Preface

This investigation was performed by the Hydraulics Laboratory (HL), U.S. Army Engineer Waterways Experiment Station (WES), for the U.S. Army Engineer District, Galveston (SWG). The study was conducted with the WES research ship simulator during the period November 1991-August 1992. SWG provided survey data of the prototype area. Current modeling was conducted by the Estuarine Processes Branch, Estuaries Division, HL.

The investigation was conducted by Mr. Dennis W. Webb, Ship Simulator Group, Navigation Branch, Waterways Division, HL, under the general supervision of Messrs. Frank A. Herrmann, Jr., Director, HL; Richard A. Sager, Assistant Director, HL; M. B. Boyd, former Chief, Waterways Division, and Dr. Larry L. Daggett, Chief, Navigation Branch. Ms. Phylliss Birchett, Civil Engineering Technician, Navigation Branch, assisted in the study. This report was prepared by Mr. Webb.

Acknowledgment is made to Dr. Thomas Rennie and Mr. Al Meyer, Engineering Division, SWG, for cooperation and assistance at various times throughout the investigation. Special thanks go to Hollywood Marine, Houston, TX, American Commercial Barge Lines, New Orleans, LA, and the Houston Pilots Association for participating in the study.

At the time of preparation of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
horsepower (550 foot-pounds (force) per second per ton (force))	83.82	watts per kilonewton
inches	2.54	centimeters
knots (international)	0.5144444	meters per second
miles (U.S. statute)	1.609347	kilometers

1 Introduction

The Houston - Galveston Navigation Channels are located along the Gulf of Mexico Coast in eastern Texas, Figure 1. These channels include the Entrance Channel, Galveston Channel, Bolivar Roads, Texas City Channel, the Gulf Intracoastal Waterway (GIWW), and the Houston Ship Channel (HSC) which branches off the Bolivar Roads Channel, traverses Galveston Bay, and ends in Houston. This report focuses only on the southern portion of Galveston Bay where the GIWW and the HSC intersect, shown in Figure 2. The HSC, which serves the Port of Houston, is one of the busiest channels in the country. As reported by Houston ship pilots, the number of ship movements recently has been approaching 1,000 per month. The amount of barge traffic, while undocumented, is many times greater. The GIWW links the HSC with the inland navigation system.

Existing Conditions and Navigation Problems

The present deep-draft navigation channel in the Galveston Bay segment of the HSC as maintained by the U.S. Army Engineer District (USAED), Galveston, is 40 ft¹ deep, below mean low tide (mlt), and 400 ft wide. The GIWW is maintained to a depth of 12 ft mlt. The intersection of the GIWW and the HSC is regarded as potentially dangerous, because tows will block part of the ship channel while turning on the east side of the intersection. Tows outbound on the GIWW from the Bolivar Peninsula turning north inbound on the HSC present the greatest safety problem, particularly during flood tide. Tidal currents up to 3.7 ft per second (fps) occur during flood tide (Figure 3) and up to 4.2 fps during ebb tide (Figure 4). In an attempt to avoid the flood tide pushing the tow toward the shoal area near buoys R22, R22A, and R24, towboat captains are forced to turn their tows in the deep-draft portion of the HSC. Due to the

¹ A table of factors for converting non-SI units of measurement to SI units is found on page vi.

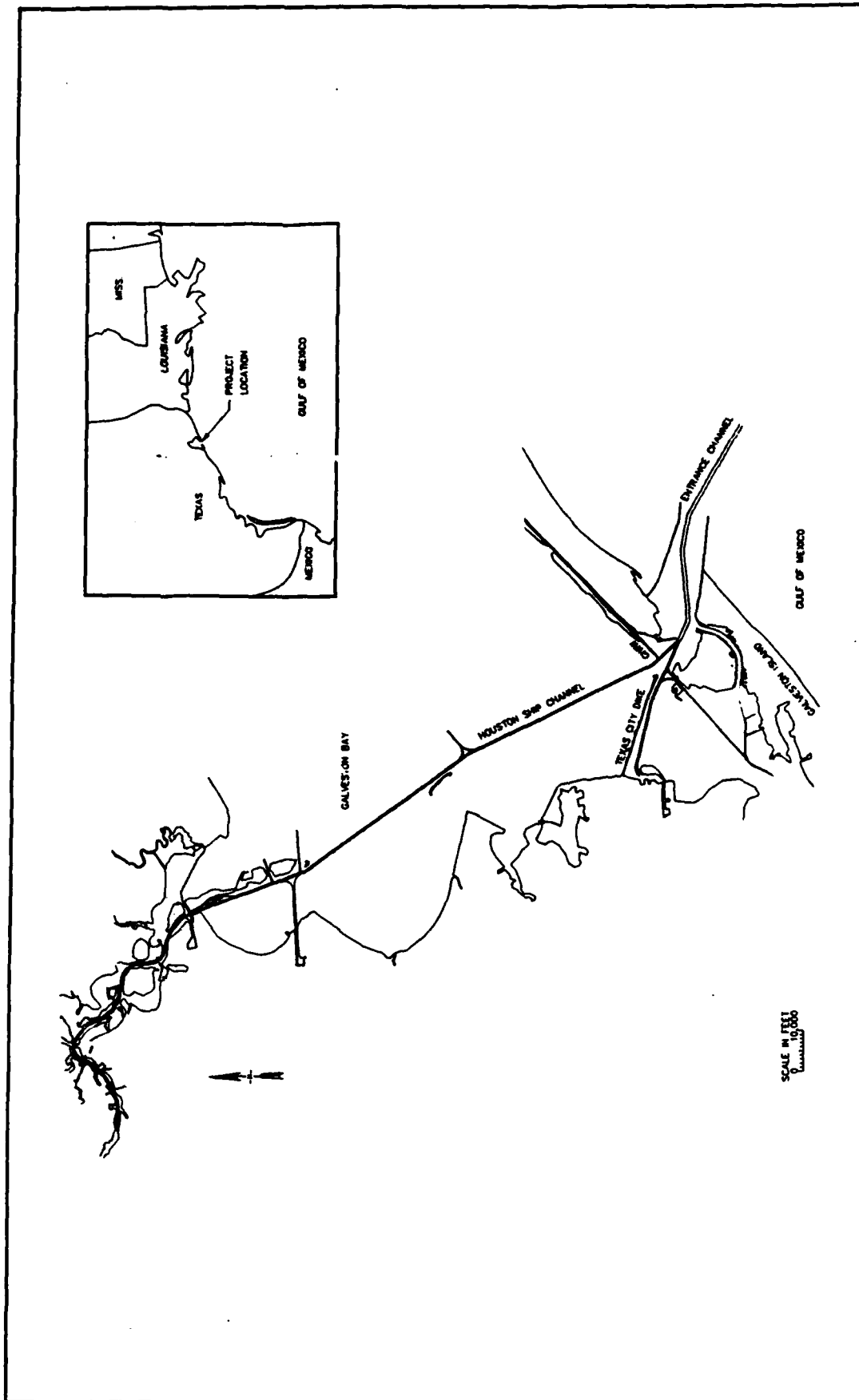


Figure 1. Project location map

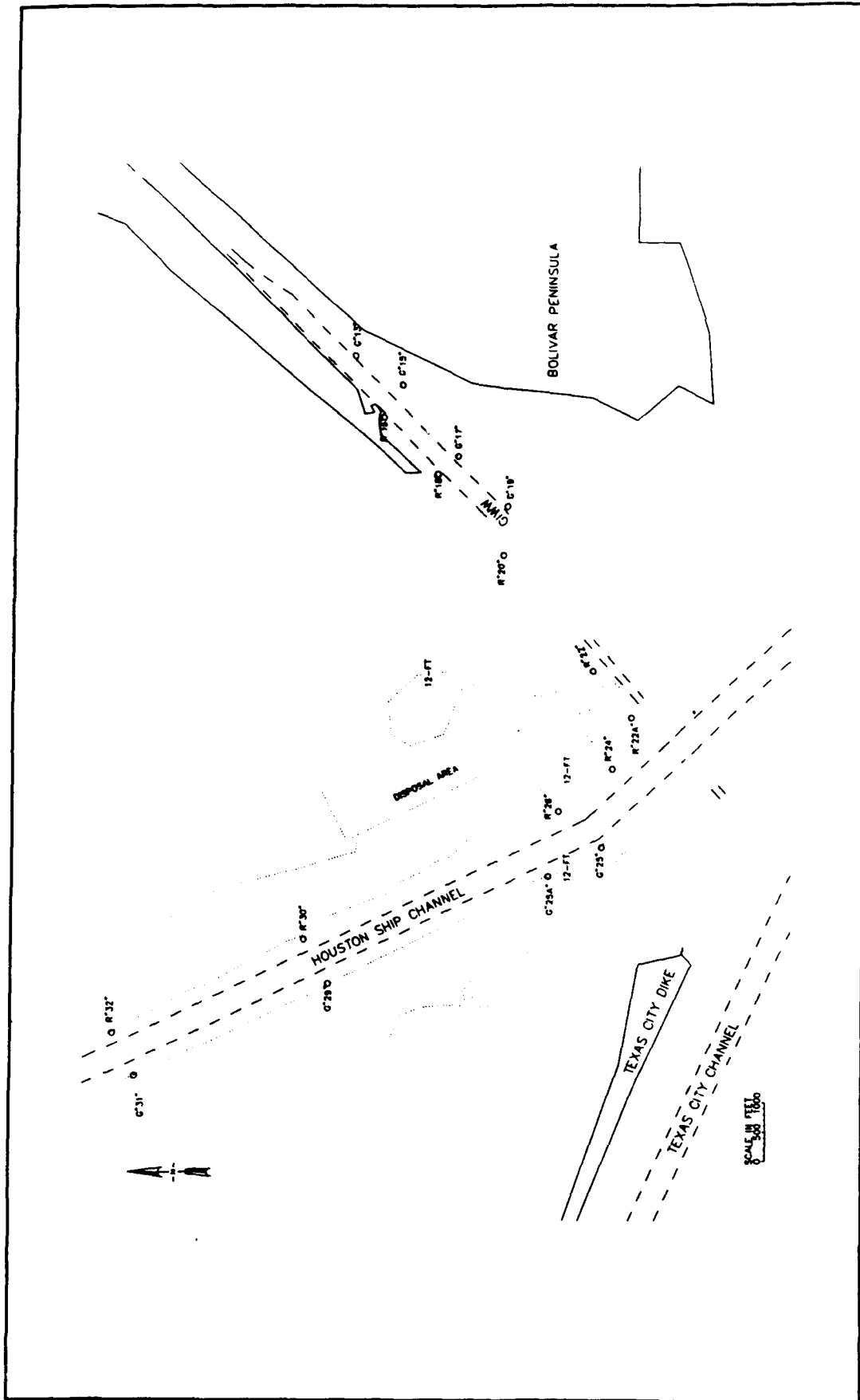


Figure 2. HSC/GIWW Intersection

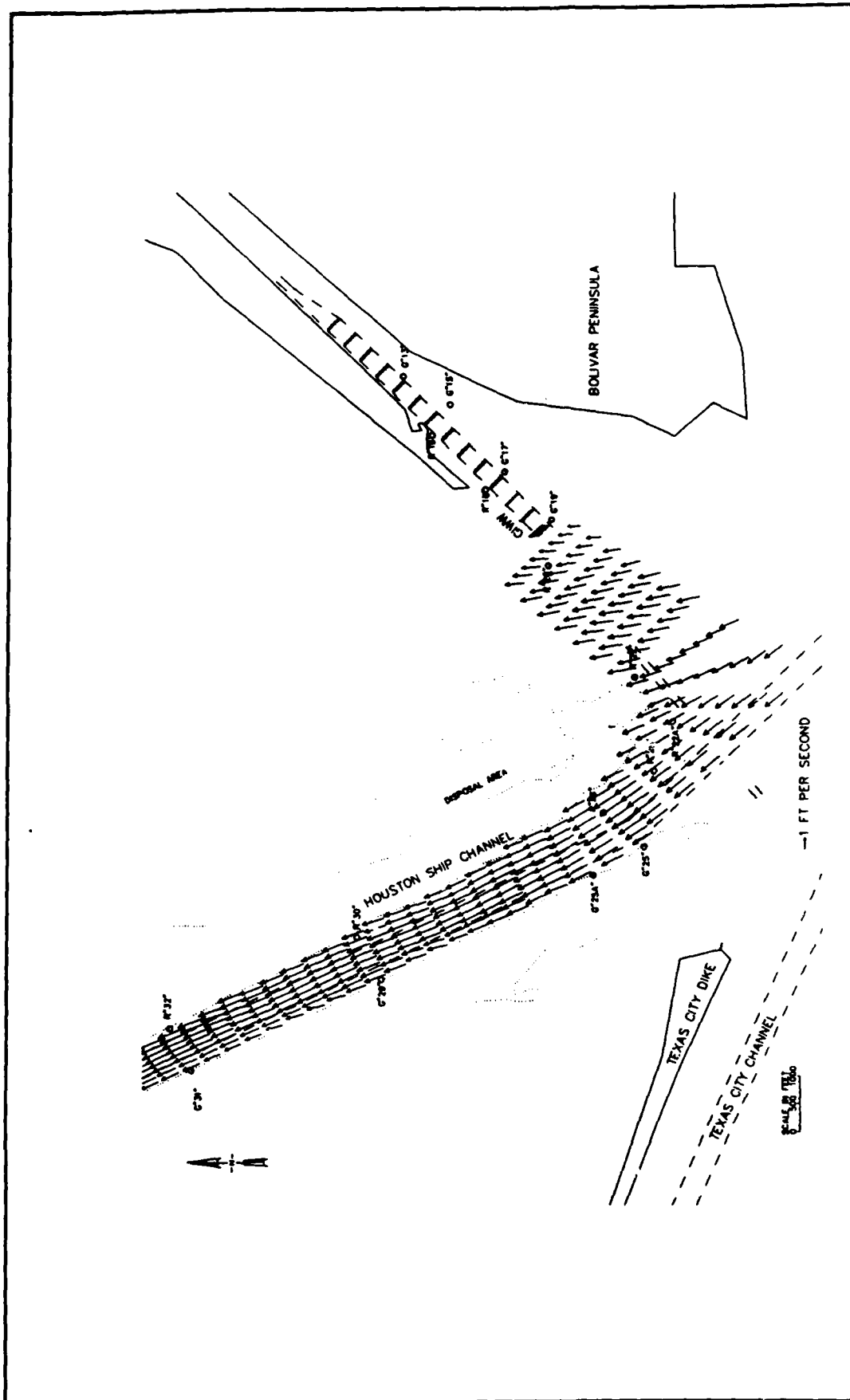


Figure 3. HSC/GIWW intersection, flood tide

heavy ship traffic, this creates a potentially dangerous situation. Since the ebb tide pushes the tow away from the shoal, the towboat captains do not have to occupy the deep-draft portion of the HSC for as long a time period. As reported by the U.S. Coast Guard (USCG) and representatives of the towing industry, tows turning to or from the western side of the intersection do not pose a safety problem.

Tows heading out of Houston and turning into the GIWW do not have the same navigational concerns as the inbound tows. Outbound tows have ample room to turn east or west in the expanse of deep water south of the intersection. The primary problem for outbound tows is entering the Bolivar Peninsula portion of the GIWW, particularly during ebb tide. The southern portion of the Bolivar Peninsula provides some protection from the flood tide currents, while the ebb tide acts on the tow until it enters the GIWW between the peninsulas. After the tow's bow is in the protected area, ebb currents continue to push its stern to the south, thus swinging the vessel counter clockwise to the north.

Proposed Channel Improvement

The USAED, Galveston, has proposed a GIWW channel improvement (Figure 5) consisting of wideners on both sides of the intersection and a phased improvement plan for the HSC (USAED, Galveston 1987). After discussions with the USCG and the towing industry, the widener on the western side of the intersection was eliminated, and all efforts were concentrated on the eastern side of the intersection. The Phase I HSC was proposed to be a minimum of 530 ft wide and 45 ft deep, mlt, and the Phase II channel was to be a minimum of 600 ft wide and 50 ft deep, mlt.

A second alternative was developed with input from the towing industry (Figure 6). A one-way cutoff for inbound tows only was designed to go from the end of the maintained GIWW at Bolivar to R32 on the HSC. This was to allow inbound tows a lesser approach angle to enter the HSC.

All channel widths and alignments tested were furnished to the Galveston District for their approval prior to testing. Existing channel bottom and bank conditions (bank slope and overbank depth) were obtained from the most recent postdredging survey conducted by the District. Bank conditions for the proposed channel were the same as for the existing channel.

Purpose and Scope of Investigation

The navigation study was conducted using the WES Hydraulic Laboratory's ship/tow simulator facility. The objective of the study was to test the proposed improvements for the GIWW/HSC intersection to ensure that

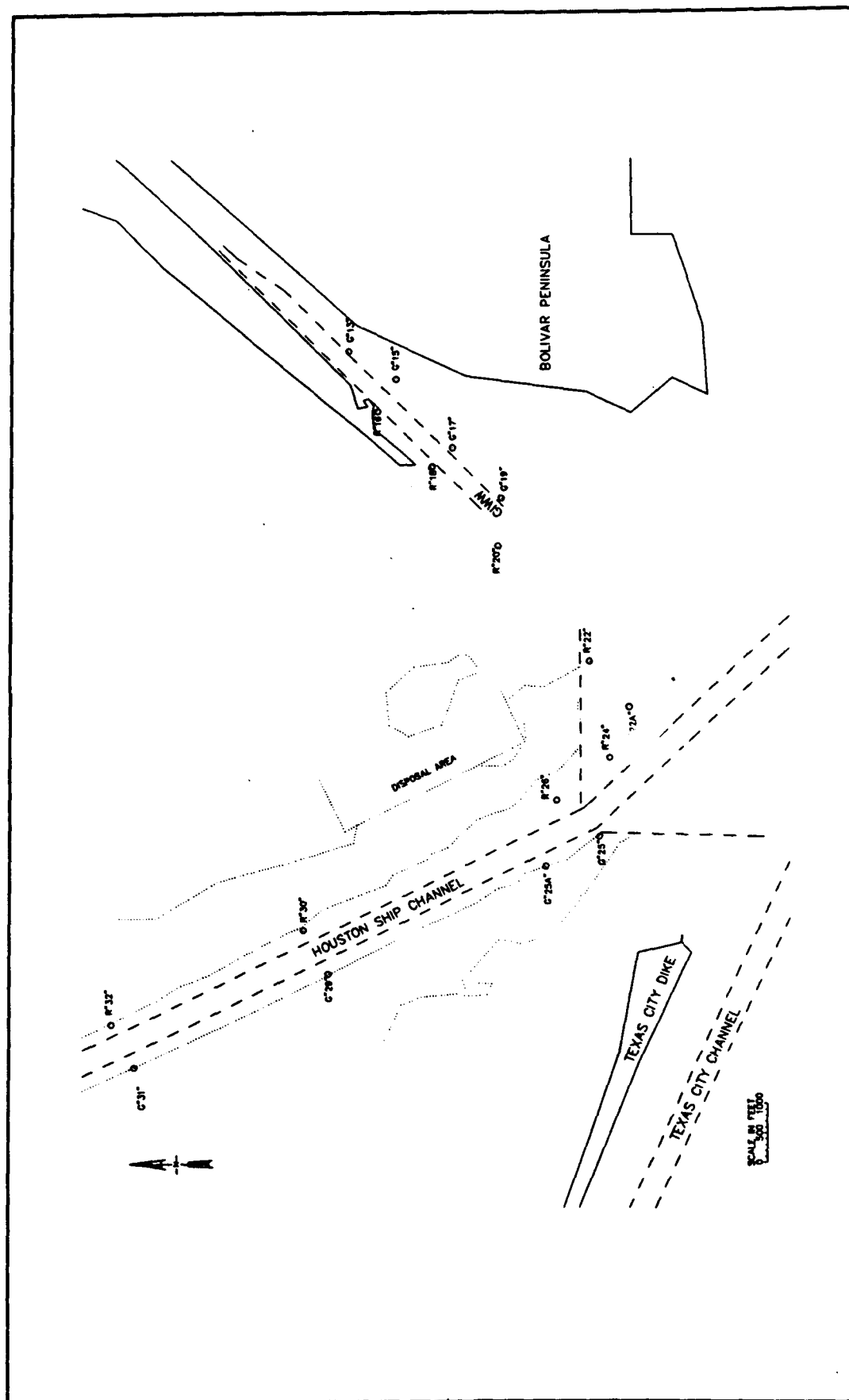


Figure 5. Proposed improvements, feasibility report

they were adequate for safe navigation. To recreate the most restrictive design situation occurring in the prototype, real-time testing was accomplished by conducting shallow-draft (tow) and a deep-draft (ship) simulations simultaneously. The two vessels were heading in opposite directions, and the simulations were timed so that meeting and passing occurred at or near the GIWW/HSC intersection.

Testing of two-way traffic (tows meeting ships) was accomplished with two simulators, one for the ship and the other for the tow. The tow simulator was operated by a towboat captain experienced with the intersection. The ship simulator was operated by a ship pilot licensed for the HSC. The simulated vessels were in visual, radar, and radio contact with each other. The simulation model replicated the actual meeting/passing maneuver as closely as possible with interactive hydrodynamics affecting two vessels moving in opposing directions.

2 Data Development

To simulate the study area, it is necessary to develop information relative to five types of input data:

- a.* Channel database contains dimensions for the existing channel and the proposed channel modifications. It includes the channel cross sections, bank slope angle, overbank depth, initial conditions, and autopilot track-line and speed definition.
- b.* Visual scene database is composed of three-dimensional (3-D) images of principal features of the simulated area, including the aids to navigation, docks, buildings.
- c.* Radar database contains the features for the plan view of the study area.
- d.* Ship data files contain characteristics and hydrodynamic coefficients for the test vessels.
- e.* Current pattern data in the channel include the magnitude and direction of the current and the water depth for each cross section defined in the channel database.

Channel

Channel cross sections are used to define the ship/tow simulator channel database. The information used to develop the channel database came from the District-furnished hydrographic survey charts of May, 1986. This was the latest information available concerning depths, dimensions, and bank lines of the channel. State planar coordinates as shown on the annual survey were used for the definition of the data. Prototype survey ranges were used to locate the simulator cross sections. If the prototype survey ranges were not spaced close enough for simulator purposes, a new range was interpolated. In areas where the prototype survey ranges did not exist, data were obtained from navigation charts.

The simulator model uses eight equally spaced points to define each cross section. At each of these points, a depth, current magnitude, and direction are required. For each cross section, the width, right and left bank slopes, and overbank depths are required. The channel depths at each of the eight points were provided by a TABS-MD model study (Lin 1992), conducted simultaneously with the development of the simulation databases, that computed the current magnitudes and directions.

The channel side slope and overbank depth are used to calculate bank force. The shallower the overbank and the steeper the side slope, the greater the computed bank effects. A small difference (1 to 2 ft) in channel bottom and overbank depth produces negligible bank forces and moments.

Visual Scene

The visual scene database was created from the same maps and charts noted in the discussion of the channel. As in the development of the channel database, the state planar coordinate system was used. Aerial and still photographs and pilot's comments obtained aboard transiting ships and tows during a reconnaissance trip to Galveston constituted other sources of information for the scene. These allowed inclusion of the significant physical features and also helped determine which, if any, features the pilots use for informal ranges and location sightings. All aids to navigation such as buoys, channel markers, buildings, docks, docked vessels, towers, ferry slips, dolphins, and tanks were included in the visual scene.

The visual scene is generated in three dimensions: north-south, east-west, and vertical elevation. As the ship progresses through the channel, the 3-D picture is constantly transformed into a two-dimensional (2-D) perspective graphic image representing the relative size of the objects in the scene as a function of the vessel's position and orientation and the relative direction and position on the ship's bridge for viewing. The graphics hardware used for the project was a stand-alone computer connected with the main computer to obtain information for updating the viewing position and orientation. This information includes parameters such as vessel heading, rate of turn, forward and lateral velocity, and position. Also, the viewing angle as set by the pilot is passed to the graphics computer for the look-around feature on the simulator console, which encompasses a 40-deg field of view. This feature simulates the pilot's ability to see any object with a turn of his head. The pilot's position on the bridge can also be changed from the center of the bridge to any position wing to wing to simulate the pilot's walking across the bridge to obtain a better view, e.g., along the edge of the ship from the bridge wing.

Radar

The radar database is used by the radar software to create a simulated radar for use by the test pilots. The radar database contains X- and Y-coordinates that define the border between land and water. The file also contains coordinates for the bank line and any structure on the bank or extending into the water such as bridges and aids to navigation. In short, these data basically define what a pilot would see on a vessel's radar. The radar image is a continuously updated plan view of the vessel's position relative to the surrounding area. Three different ranges of 0.5 mile, 0.75 mile, and 1.5 miles were programmed to enable the pilot to choose the scale needed. A second radar screen with a 0.25-mile range was also provided.

Current

A current database contains current magnitude and direction at eight points across the channel at each of the cross sections defined in the channel. Channel bottom depths are also given at each of these eight points and are included in the channel definition. Interpolation of the data between cross sections provides continuous and smooth current patterns.

The tidal current was derived from the TABS-MD model study (Lin 1992). Results from this hydrodynamic model were used to develop the current databases. Because the alignment of the existing channel and the alignment of the proposed channel is somewhat similar, and to keep within time and cost restraints, the hydrodynamic model grid was not modified to reflect the change in alignment. However, the proposed channel improvements significantly increased the volume of water in the bayou area, thus reducing the magnitude of the currents. To estimate the currents in the improved channels, currents were calculated with the existing channel widened to 530 ft and deepened to 45 ft and also with the existing channel widened to 600 ft and deepened to 50 ft. The results of these runs were then assumed to reflect the currents in the realigned channels.

Test Vessels

The vessel files contain characteristics and hydrodynamic coefficients for the test vessels. These data are the computer's definition of the ship, i.e., the ship model. The coefficients govern the reaction of the ship to external forces, such as wind, current, waves, banks, underkeel clearance, ship/ship interaction and internal controls, such as rudder and engine rounds-per-minute commands. The numerical ship models for the HSC simulations were developed by Tracor Hydraulics, Inc., Laurel, MD (Ankudinov 1991). In addition, the bow of the ship would also be seen in

the visual scene by the pilot from the ship bridge. Visual images of the ship bows for all design ships had been created for previous studies at the U.S. Army Engineer Waterways Experiment Station (WES). The test ships were chosen based on the District's economic analysis of future shipping business and operations. The tow used as the design vessel for both existing and proposed conditions was a four-barge tow, 1,169 ft long, 59 ft wide, drafting 9 ft. To test the worst-case scenario, it was decided to test the proposed GIWW alternatives coupled with the Phase II (600 ft by 50 ft) HSC. The inbound ships were tankers carrying oil to Houston, and the outbound ships were bulk carriers exporting grain. The ships used as design vessels are described in Table 1.

Table 1 Design Ship for Simulation			
Channel	Ship Type	Tonnage	Dimensions (ft)
Existing	Tanker	132K	920 x 144 x 39
Existing	Bulk Carrier	93K	775 x 106 x 39
Phase II	Tanker	175K	1,013 x 173 x 49
Phase II	Bulk Carrier	155K	971 x 140 x 49

As in the simulations of the Bay and Bayou Segments, the design vessels were loaded to 1-ft underkeel clearance.

3 Navigation Study

Formal pilot testing was conducted with six professional towboat captains experienced in the project area, two professional pilots licensed for the Houston Ship Channel, and two WES employees. Local professional mariners incorporated their experience and familiarity with handling vessels in the study area in the project navigation evaluation. The tests were conducted in Vicksburg, MS, on the WES ship/tow simulator.

Validation

The HSC portion of the simulation databases had been validated during the previous navigation study for the Galveston Ship Channel and the Houston/Galveston Entrance Channels (Webb in preparation). The GIWW portion of the simulation databases was validated with the assistance of two ship captains who were extremely familiar with navigation conditions in the area. The following information was verified and fine tuned during validation:

- a. The channel definition.**
 - (1) Bank conditions.
 - (2) Currents.
- b. The visual scene and radar image of the study area.**
 - (1) Location of all aids to navigation.
 - (2) Location of buildings visible from the vessel.

The design vessel models had been validated and used in simulation tests of the Houston Ship Channel - Bay segment (Hewlett 1994).

To validate the reaction of the vessel to bank forces, several simulation runs were made with the vessel transiting the entire study area. Special at-

tention was given by the captain to the response of the ship to the bank forces. Problem areas were isolated, and the prototype data for these areas were examined. The values for the overbank depth, the side slope, or the bank force coefficient were adjusted. Simulation runs were then undertaken through the problem areas, and if necessary, further adjustment was made. This process was repeated until the captain was satisfied that the simulated vessel response to the bank force was similar to that of an actual vessel passing through the same reach in the prototype.

The reaction of the vessel to current forces was verified by conducting several simulation runs over the entire study area. The captain was instructed to pay attention to the current effects. The captain was satisfied that the vessel response to the currents was similar to responses he had actually experienced.

The visual scene and radar image of the study area were checked during validation of the other parameters. If the pilot noticed something missing or misplaced, this was checked against prototype information and adjusted accordingly.

Preliminary Design Testing

To assure that the alternatives to be tested during real-time simulation would be reasonable and workable solutions to the problems to be addressed, it was decided that a preliminary testing exercise would be appropriate.

A preliminary testing team assembled at WES for 3 days of preliminary design testing. In addition to the WES staff, the team consisted of two towboat captains who regularly transit the intersection of the GIWW and HSC and two officers in the USCG. The ship pilots were not involved because this was a preliminary design, and a reasonable working alternative could be designed using tows only. The towboat captains operated the simulator in real-time mode and provided insight to problems they were having while transiting the reach. The USCG representatives provided guidance on channel marking and channel operation. Testing was done in an iterative mode with solutions being offered to navigation problems during a simulator test run, those solutions being implemented into the simulation model, and additional test runs being made to determine new navigation concerns.

During preliminary testing, it was agreed by all team members to omit the one-way cutoff from further consideration as a channel alternative for the following reasons:

- a. The turn from Bolivar Peninsula into the cutoff was too difficult during ebb tide.

- b. Deep-draft ships might have adverse effects from the cutoff due to a change in bank effects and possible crosscurrents entering the ship channel near R32.
- c. Fear that ships would pull the water out of the cutoff as they passed, thus breaking up the barges of any tows in the cutoff.
- d. Concerns by the USCG about the operation of a one-way cutoff channel and preventing outbound tows from using it.

At the conclusion of the preliminary test program, it was unanimously decided that a modification of the General Design Memorandum widener (Figure 5) be used for the full test program (Figure 7). This widener allowed the tows a more gradual turn into the HSC. Only three buoys are required to mark this cutoff. Buoy R22A was not required. In addition, it was determined that flaring the southern edge of the GIWW near Bolivar Peninsula would allow outbound tows safer entrance into that portion of the GIWW. The channel was flared by moving the edge of the channel near C19, 150 ft to the south. The channel flare was designed as an add-on to the project and was not part of the interactive design phase.

Test Procedures

Tests were conducted in a random order. This was done to prevent prejudicing the results as would happen if, for example, all existing conditions were run prior to running the plans. The skill gained at operating the simulator could show the plans to be easier than they might really be.

The simulator tests were evaluated based on pilot ratings and ship tracks. The following section will present these methods of analysis.

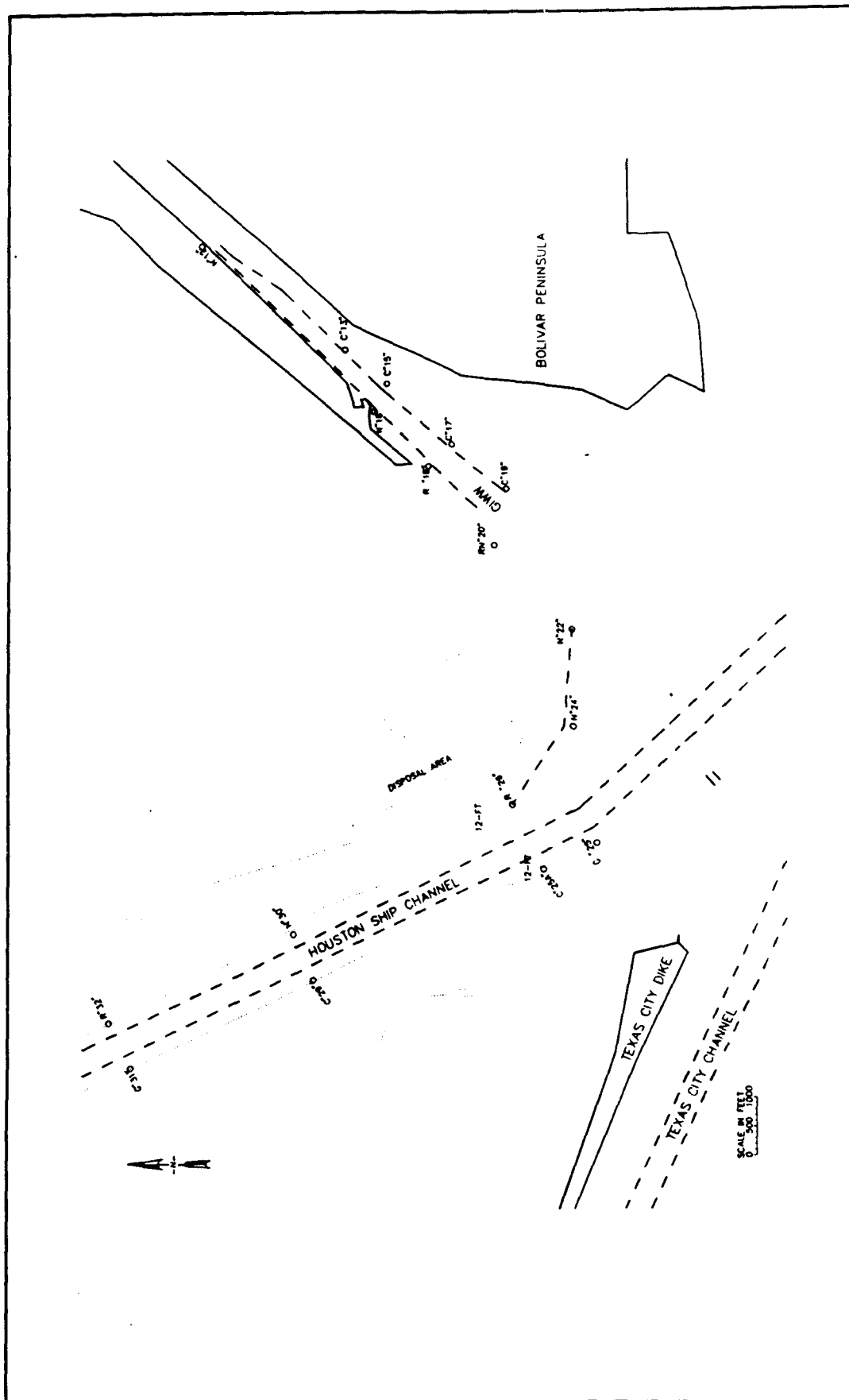


Figure 7. Modified widener

4 Study Results

Vessel Track Plots

Track plots of the real-time testing conducted at the WES ship/tow simulator are presented in Plates 1 through 47. The heading referred to in the title of each plate corresponds to the heading of the tow. Thus, enclosures labeled "Inbound" refer to a tow heading out of the Bolivar Peninsula and toward Houston, and "Outbound" refers to tows leaving Houston and turning east into the Bolivar Peninsula. Of course, inbound tows meet and pass outbound ships and outbound tows meet and pass inbound ships. Six towboat captains participated in the test program and are labeled 1 through 6 on the title of each plate. Two ship pilots, representing the Houston Pilots Association, took part in the study with one of the ship pilots participating in over 80 percent of the total runs. Therefore, because this is essentially a tow study, the ship pilots were not assigned numbers to be shown on each track plot.

Other information shown on each track plot includes the authorized channel limits, land boundaries, aids to navigation, and the 12-ft contour. The 12-ft contour is included because the authorized depth of the GIWW is 12 ft. Track plots of vessels operating out of the channel but remaining clear of the 12-ft contour are assumed to be operating in safe navigation conditions. Vessels entering an area enclosed by the 12-ft contour do not necessarily go aground because the tow drafts 9 ft. Towboat captains who are very experienced in this area will go "into the flats" and still maintain an adequate underkeel clearance. However, this area serves a large number of operators, many of whom are not familiar enough with local conditions to safely navigate unmarked areas. Therefore, for this report, if the tow enters the 12-ft contour, even if the pilot does not ground the tow, it is assumed that he is operating in a less than desirable situation.

So that they show up legibly on the track plots, buoys are plotted as a point encompassed by a 100-ft-diam circle. Therefore, a tow that "clips" the edge of the buoy symbol in a track plot did not hit the buoy during the simulation run.

Most of the tests conducted were for ship/tow meeting and passing. However, four runs were conducted during an absence of the ship pilot. The results from these runs are included in this report along with the results of the two-way runs.

Four different incidents that could occur during testing are used to evaluate the results of the runs. They are as follows:

- a. The tow crossing the 12-ft contour line. As stated before, the tow would not always be aground in this situation.
- b. The tow crossing the authorized channel inside Bolivar Peninsula. The tow is always assumed to have run aground due to steep side slopes.
- c. The tow hitting a buoy. This is a major problem in real life. Some buoys near Bolivar Peninsula are replaced weekly.
- d. The ship leaving the authorized channel. If the ship's leaving the channel was not caused by the tow, it is not considered in evaluating the improvements to the GIWW/HSC bend widener.

Existing conditions, inbound, flood tide

Track plots of all runs in the existing channel, inbound with a flood tide, are shown in Plates 1 through 5. The typical operating procedure for this maneuver is to head south upon leaving the area protected by the Bolivar Peninsula and move the tow along the buoy line defined by buoys G17 and G19, in preparation for a set to the north by the strong flood tide. Some of the towboat captains (Plates 1, 3, and 4) turned in front of the ship and met the ship "on two whistles," or starboard to starboard. It should be noted that this procedure required that the tows cross the 12-ft contour near G25 and requires that the tow pass directly in front of the ship. Other runs (Plates 2 and 5) met the ship "on one whistle," or port to port. A summary of all inbound runs conducted in the existing channel with a flood tide is presented below.

Plate	Crossing 12-ft Contour	Leaving Channel	Hitting Buoy	Ship Leaving Channel
1	Yes	No	Yes - G25	No
2	No	Yes	Yes - G17	Yes
3	Yes	No	Yes - G25A	No
4	Yes	No	Yes - G25A	No
5	No	No	No	Yes
Totals	3	1	4	2

Proposed conditions, inbound, flood tide

Track plots of all runs in the proposed channel, inbound with a flood tide, are shown in Plates 6 through 11. For all of these runs, the ship and tow met on one whistle. During one run (Plate 11), the tow hit R20 due to the flood currents. The towboat captain in Plate 11 moved the vessel farther south before turning toward Houston and did not take advantage of the proposed cutoff. In actuality, this run is similar to those conducted under existing conditions. Two other captains (Plates 7 and 8) also operated their tow closely to the existing manner of operation. This is not an uncommon occurrence because these operators have had years of experience with the existing situation and only a short time with the proposed conditions. Plates 9 and 10 show the tows slightly crossing the channel edge between G17 and G19. However, the captains had their tow in the exact position that they wanted them, just inside of the buoy line defined by G17 and G19. This is in accordance with standard tow operating procedure. Towboat captains realize that even though buoys are located just off the channel edge, the USCG positions buoys such that a vessel does not ground on the channel side of the buoy. This is verified by the fact that, in actuality, so many buoys in this reach are hit by tows without the occurrence of an incident of grounding. Therefore, these incidents of leaving the channel (Plates 9 and 10) were omitted from the summary table. One pilot (Plate 8) hit G17 while attempting this maneuver. The only other undesirable action occurred when one tow (Plate 9) came within 42 ft of the ship at the moment of meeting/passing. Although a collision did not occur, this is too close and was caused by the tow's not staying closer to the buoy R26. It should be noted that this was the captain's first run in the proposed channel. A summary of all inbound runs conducted in the proposed channel with a flood tide is presented.

Plate	Crossing 12-ft Contour	Leaving Channel	Hitting Buoy	Ship Leaving Channel
6	No	No	No	No
7	No	No	No	No
8	No	Yes	Yes - G17	No
9	No	No	No	No
10	No	No	No	No
11	No	Yes	Yes - R20, G17	No
Totals	0	2	2	0

Existing conditions, inbound, ebb tide

Track plots of all runs in the existing channel, inbound with an ebb tide, are shown in Plates 12 through 16. Although none of the tows

crossed the 12-ft contour during these tests, the ship left the HSC at one time during each run. This occurred at the point of meeting/passing during four of the five tests (Plates 12, 13, 15, and 16). The ship's leaving the HSC, which occurred south of meeting/passing during one test (Plate 14), was caused by the ship pilot's missing his turn, and therefore, this incident was omitted from the summary table. Plate 14 reveals that the tow was directly in front of the ship for a substantial period of time when the vessels were less than four ship lengths apart. A summary of all inbound runs conducted in the existing channel with an ebb tide is presented.

Plate	Crossing 12-ft Contour	Leaving Channel	Hitting Buoy	Ship Leaving Channel
12	No	No	Yes - G19	Yes
13	No	No	No	Yes
14	No	No	No	No
15	No	No	No	Yes
16	No	No	Yes - G19	Yes
Totals	0	0	2	4

Proposed conditions, inbound, ebb tide

Track plots of all runs in the proposed channel, inbound with an ebb tide, are shown in Plates 17 through 21. All five runs conducted were completed without incident, therefore a summary table is not presented for this scenario.

Existing conditions, outbound, flood tide

Track plots of all runs in the existing channel, outbound with a flood tide, are shown in Plates 22 through 27. One of these runs (Plate 26) was for the tow only. During two of these runs (Plates 22 and 23), the tow crossed the 12-ft contour near the HSC/GIWW intersection. During three of the runs, the tow went aground inside of Bolivar Peninsula, and another run (Plate 27) was aborted when it became obvious the tow was not going to make the turn after being swept south by the currents. A summary of all outbound runs conducted in the existing channel with a flood tide is presented on the following page.

Proposed conditions, outbound, flood tide

Track plots of all run in the proposed channel, outbound with a flood tide, are shown in Plates 28 through 34. A summary of all outbound runs

Plate	Crossing 12-ft Contour	Leaving Channel	Hitting Buoy	Ship Leaving Channel
22	Yes	No	Yes - G24	No
23	Yes	Yes	Yes - G13	No
24	No	No	No	No
25	No	Yes	Yes - G15	Yes
26	No	Yes	Yes - G17, G15	N/A
27	No	Yes	Yes - R26, R24	No
Totals	2	4	5	1

conducted in the proposed channel with a flood tide is presented below. Although three track plots (Plates 28, 32, and 34) show the vessel leaving the authorized channel limits, they were on the channel side of the buoy line and are not considered as leaving the channel.

Plate	Crossing 12-ft Contour	Leaving Channel	Hitting Buoy	Ship Leaving Channel
28	No	No	Yes - G19	No
29	No	Yes	Yes - G19	No
30	No	Yes	No	No
31	Yes	No	Yes - R22	No
32	No	No	No	N/A
33	Yes	Yes	Yes - R24	No
34	No	No	No	Yes
Totals	2	3	4	1

Existing conditions, outbound, ebb tide

Track plots of all runs in the existing channel, outbound with an ebb tide, are shown in Plates 35 through 41. A summary of all outbound runs conducted in the existing channel with an ebb tide is presented.

Plate	Crossing 12-ft Contour	Leaving Channel	Hitting Buoy	Ship Leaving Channel
35	Yes	No	Yes - G25, G19	No
36	Yes	No	Yes - G19	N/A
37	No	No	No	No
38	Yes	Yes	No	No
39	No	Yes	No	No
40	Yes	Yes	Yes - G19, R18	Yes
41	No	Yes	Yes - R26, R24	Yes
Totals	4	4	3	2

Proposed conditions, outbound, ebb tide

Track plots of all runs in the proposed channel, outbound with a ebb tide, are shown in Plates 42 through 47. A summary of all outbound runs conducted in the proposed channel with an ebb tide is presented.

Plate	Crossing 12-ft Contour	Leaving Channel	Hitting Buoy	Ship Leaving Channel
42	No	No	No	N/A
43	Yes	No	No	No
44	No	Yes	Yes - G19	No
45	No	No	No	No
46	No	Yes	No	No
47	No	Yes	No	No
Totals	1	3	1	0

Pilot ratings

After each run was completed, both the tow and ship captains were asked to evaluate the difficulty of each run on a scale of 1 to 10, with 10 being the most difficult. The results were averaged and are presented in Figure 8. The towboat captains rated the proposed plan as significantly less difficult for all conditions. The ship pilots felt conditions were approximately unchanged for flood tide, inbound and outbound. The ship captains felt the existing channel was more difficult for inbound runs with ebb tide, but that the proposed channel was more difficult for outbound runs with ebb tide. However, the ship pilots were operating a much larger

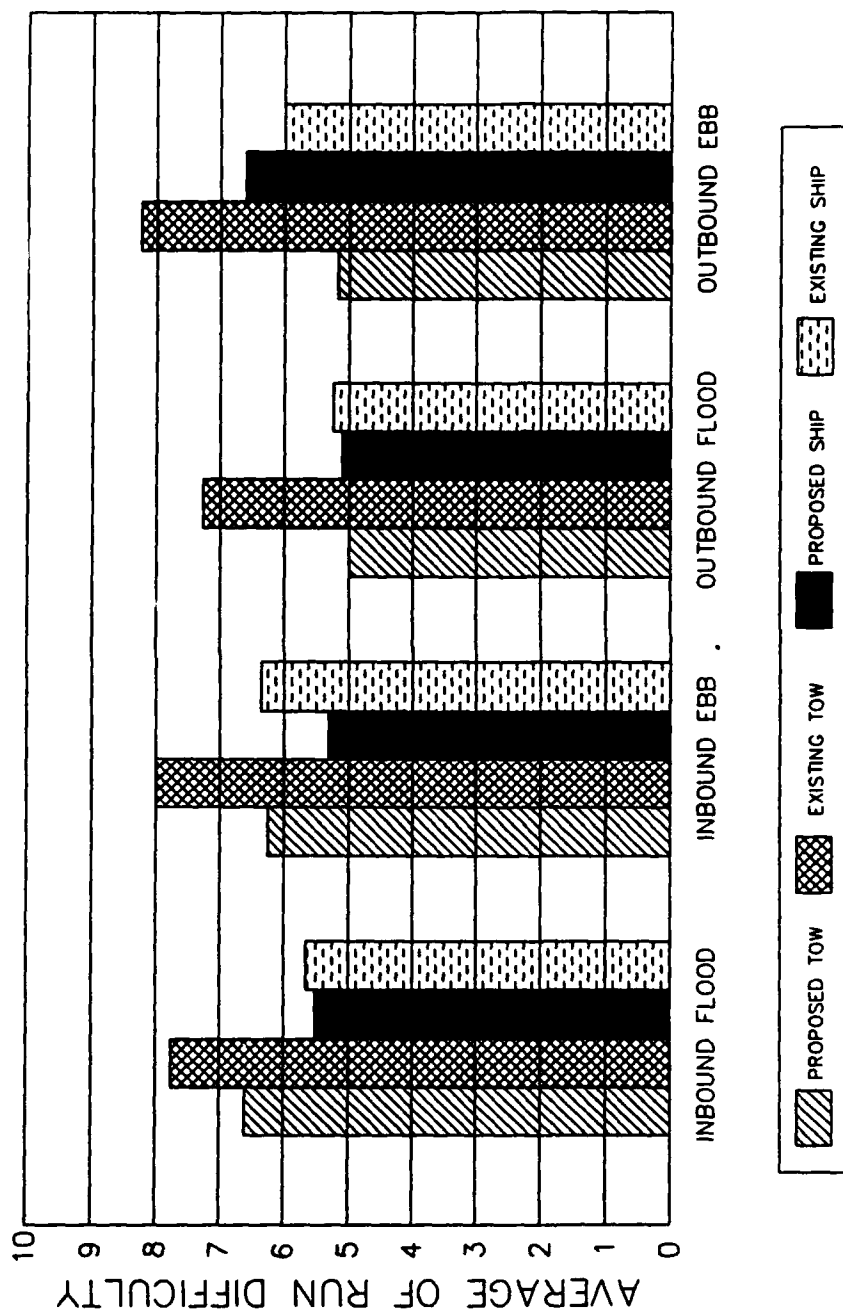


Figure 8. Pilots' ratings

vessel for the proposed condition, especially the outbound tow runs where they were on an inbound tanker.

Final Questionnaire

The towboat captains were given a final questionnaire to get their thoughts on the two areas of navigation concern. The questions and their responses are as follows.

Do you feel the widener at the intersection will improve navigation safety? Be specific in regard to current, heading, meeting another vessel, etc.

"Yes, it will improve the overall safety at the intersection."

"Yes indeed!"

"I feel the new channel will be a much needed improvement. With a flood tide the intersection will be much safer place to meet ships and tows."

"I strongly think that widening the channel would improve tow making the turn either way going inbound/outbound when either ebb or flood. I would recommend this project, also it would give you a lot more room to stay clear of ship traffic & more room to work your tow around for a safe meeting situation."

"The widening of the intersection would greatly reduce the potential for a collision in all aspects of navigating the GIWW and Houston Ship Channel intersection. This would allow for more maneuverability in what is a difficult area as it now exists."

What is your opinion of the widening on the southern edge of the Bolivar Peninsula portion of the GIWW?

"I think it is a good idea. It will allow more room for stabbing the hole, which at the present time can be a bad situation."

"Doing it would make a lot safer navigation channel than we now have."

"I think the widening of the channel will give you more room to work with the different tide and meeting of tows."

"This would help in a lot of cases when you have ebb or flood tide & even would improve meeting a tow that may be coming out of Bolivar while you are trying to come in."

"This would be advantageous during flood tide turn down toward Galveston to round-up in order to turn back to Houston to see any outbound traffic on the one whistle safely. This would also help outbound tows riding an ebb tide turn into Bolivar, giving more room to line up in the GIWW."

5 Recommendations

Based on the simulation tests of the modified plan described earlier in this report (Figure 7), it is recommended that the intersection of the GIWW and HSC be widened and marked as proposed. This widener allowed inbound tows to safely turn toward Houston without having to turn into the HSC. All inbound tows operating in the proposed channel safely met and passed an outbound ship port to port. The buoy system required to mark this turn is less complex than that currently in use. Buoys were hit less often in the proposed channel, which will result in a safer channel and less maintenance by the USCG. Therefore, the proposed widener will provide safer navigation conditions for the occasional, as well as for the frequent, user.

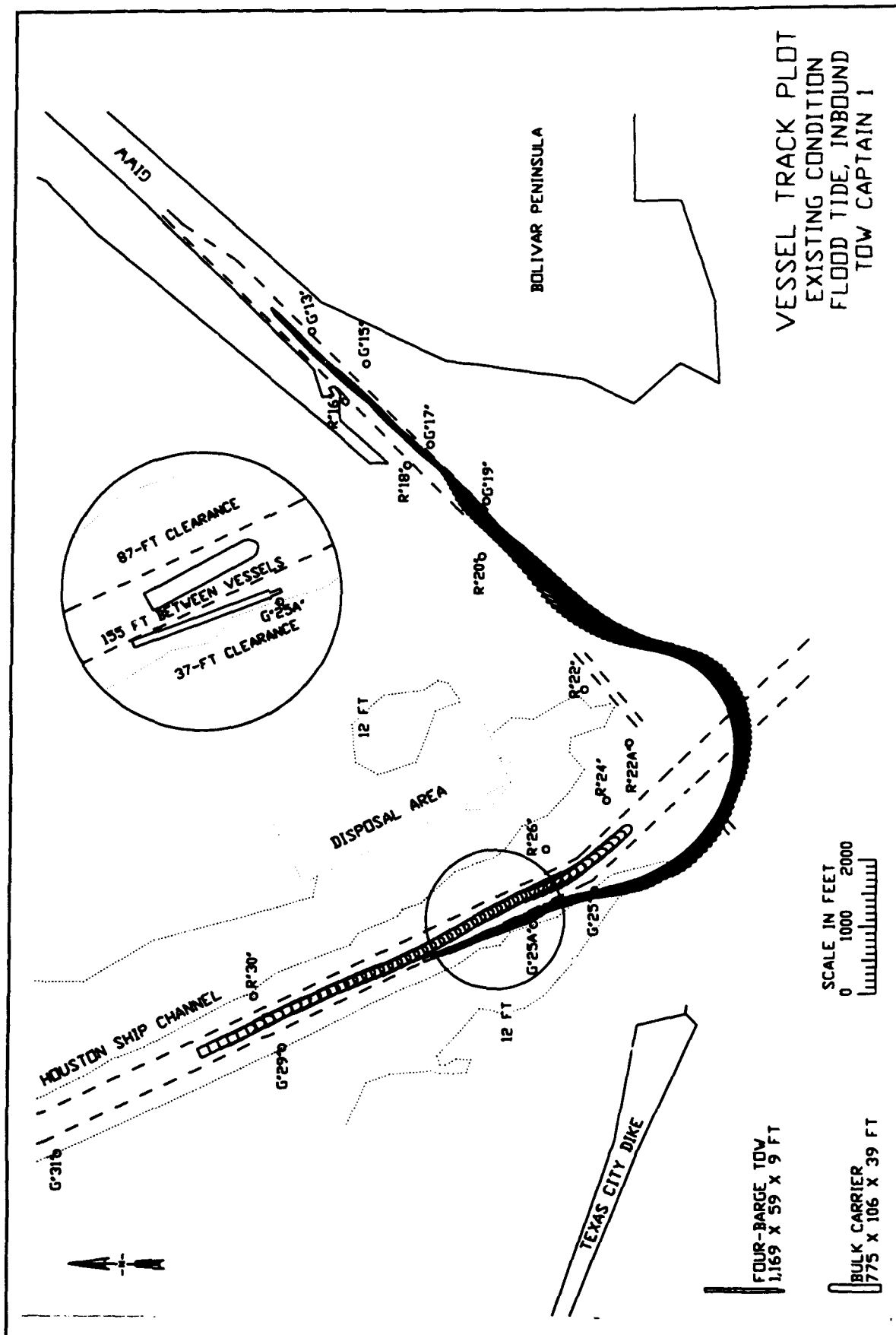
Analysis of the proposed channel flare west of the Bolivar Peninsula does not lead to an unequivocal conclusion as in the case of the HSC/GIWW intersection widener. Although it allows inbound tows to turn south sooner when facing a flood tide, for the most part, the widener is designed to assist tows outbound from Houston to enter the Bolivar area. There were numerous cases, both proposed and existing, where the tow went aground, hit a buoy, or both, when trying to enter the GIWW at Bolivar. Conditions for ebb currents were somewhat better, particularly in incidents of hitting buoys, the effects on ships, and potential grounding in the HSC. However, flood current conditions were not much improved. It is important to remember that these tests were conducted with extremely strong tidal currents. All towboat captains who participated in the test program stated that the currents for both ebb and flood were stronger than those they normally experience. In the real world, if the currents are this strong, the tows can wait for the currents to subside. Of course, this hinges upon whether or not they have been informed of the current conditions.

Based on the track plots and the captains' responses, widening the GIWW at Bolivar (Figure 7) improved the maneuver even under these difficult conditions, particularly for strong ebb conditions. Therefore, it is recommended that the proposed channel be built as tested or undertake a pretesting program similar to that used to design the widener at the HSC/GIWW intersection to further improve the design layout.

The proposed improvements to the HSC/GIWW intersection and the Bolivar Peninsula portion of the GIWW result in significant increases in navigation safety in this area. The safety benefits of this project will be of equal or greater value when combined with either the existing HSC or the Phase I HSC. Therefore, we recommend that these improvements be built as soon as possible and that they not be dependent on the proposed deepening of the HSC.

References

- Ankudinov, V. (1991). "Development of maneuvering simulation models for five full form vessels for use in the WES Houston Ship Channel (HSC) navigation study," Technical Report 90062.0122, prepared for U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, by Tracor Hydronautics, Inc., Laurel, MD.
- Hewlett, J. Christopher. (1994). "Ship navigation simulation study, Houston-Galveston Navigation Channels, Texas; Report 1, Houston Ship Channel, bay segment," Technical Report HL-94-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- Lin, Hsin-Chi J. (1992). "Houston-Galveston Navigation Channels, Texas project; Report 2, Two-dimensional numerical modeling of hydrodynamics," Technical Report HL-92-7, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.
- U.S. Army Engineer District, Galveston. (1987). "Final feasibility report and environmental impact statement, Galveston Bay area navigation study," Galveston, TX.
- Webb, Dennis W. "Ship navigation simulation study, Houston-Galveston Navigation Channels, Texas; Report 3, Galveston Ship Channel and Houston-Galveston entrance channels" (in preparation), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.



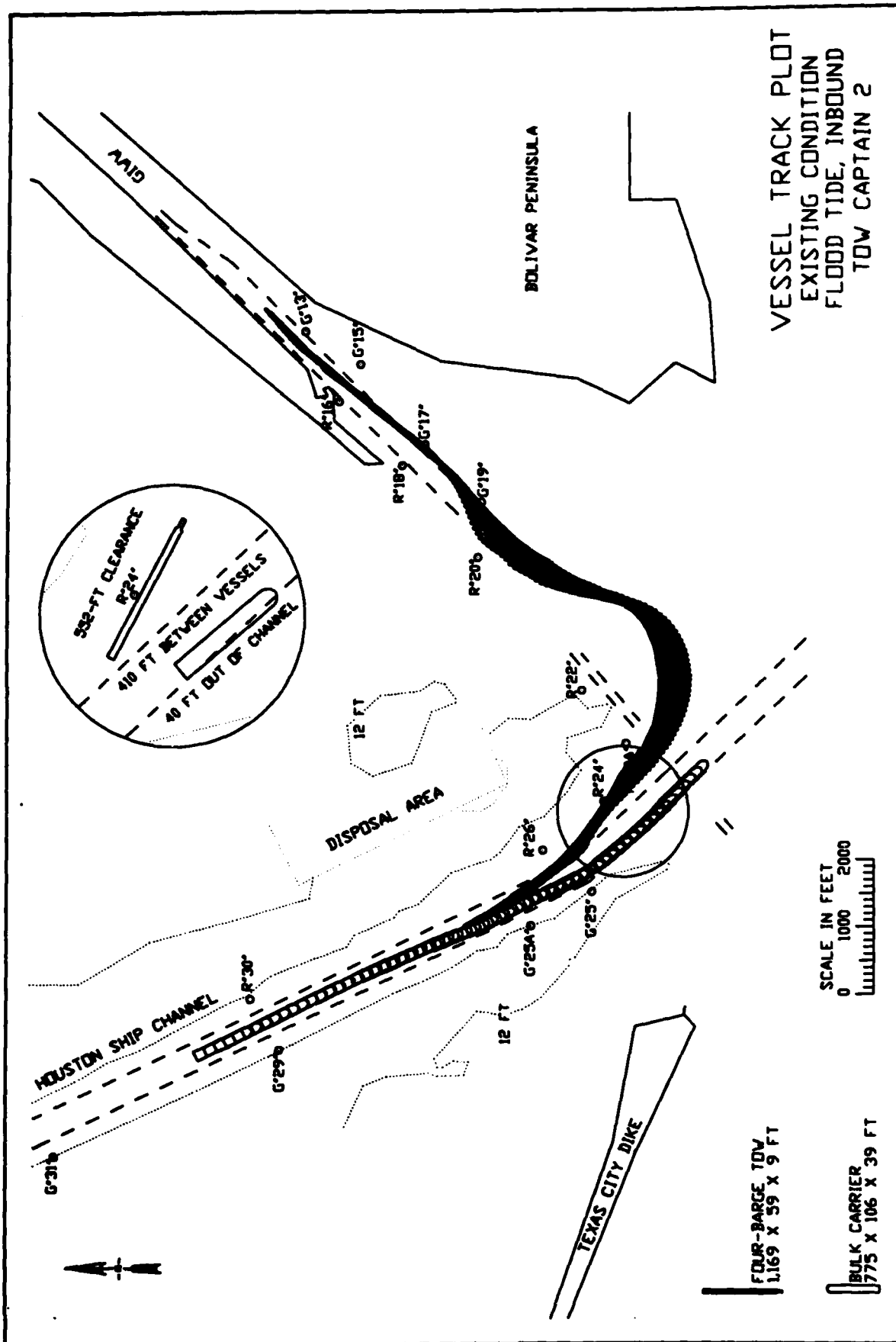
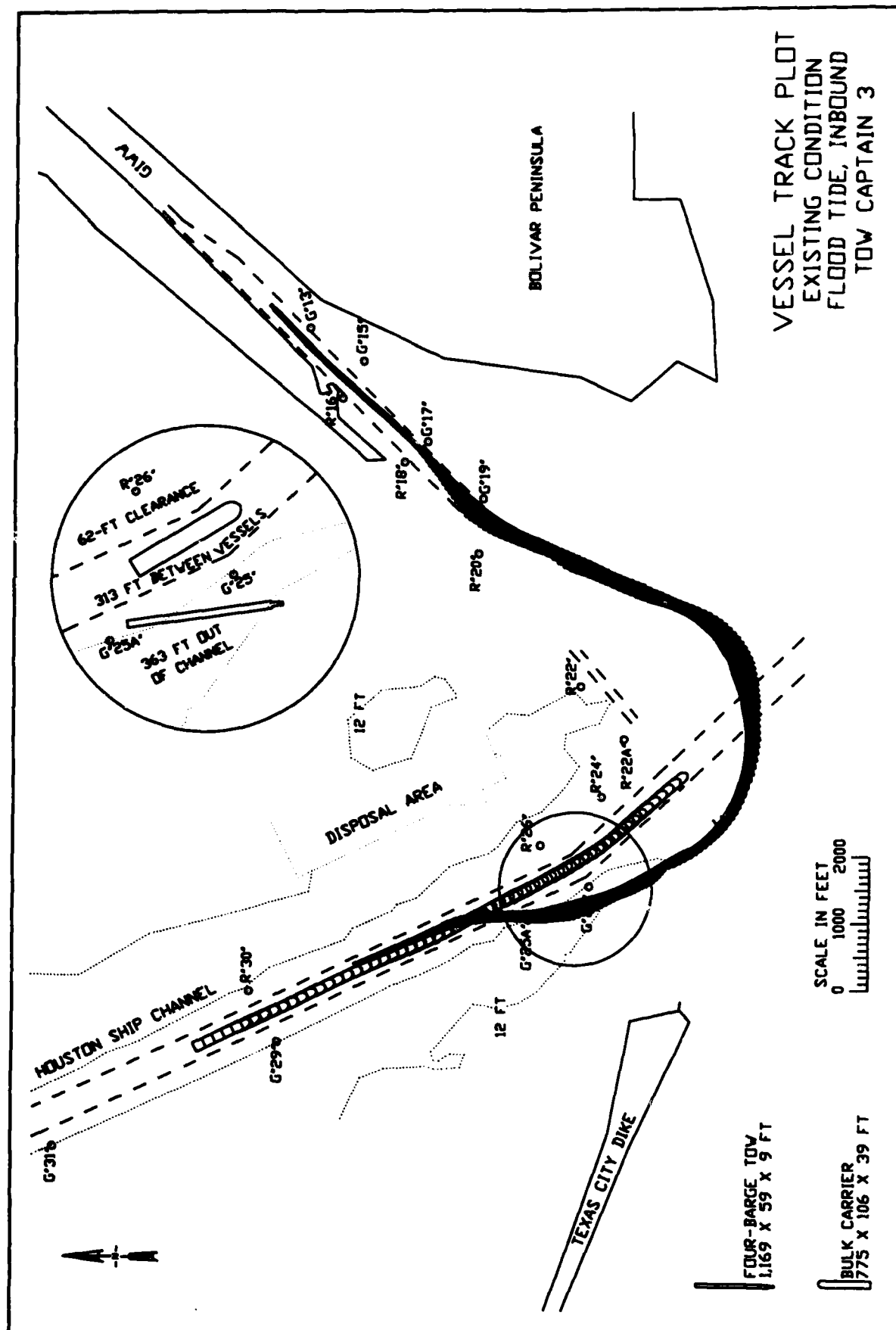


Plate 2



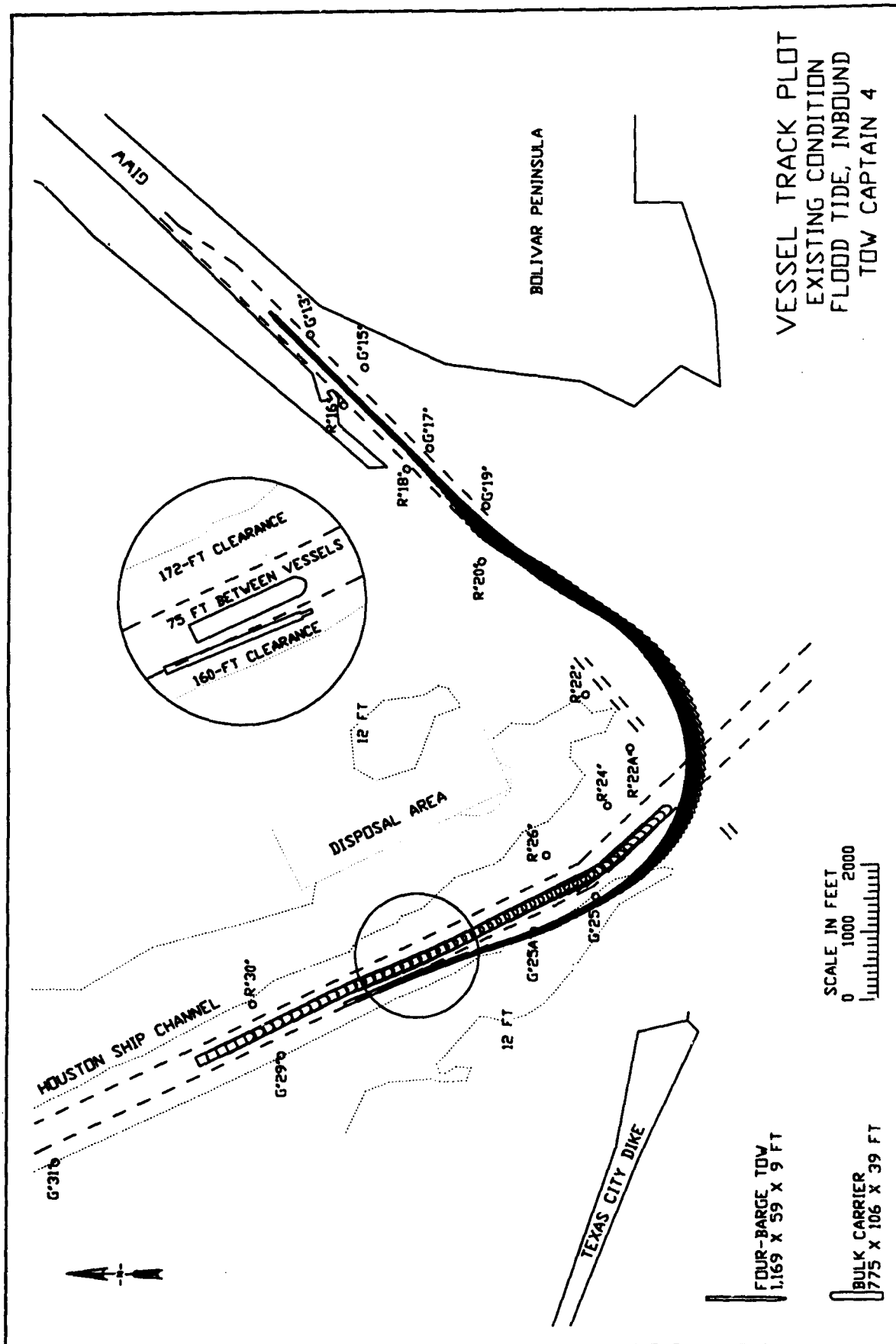
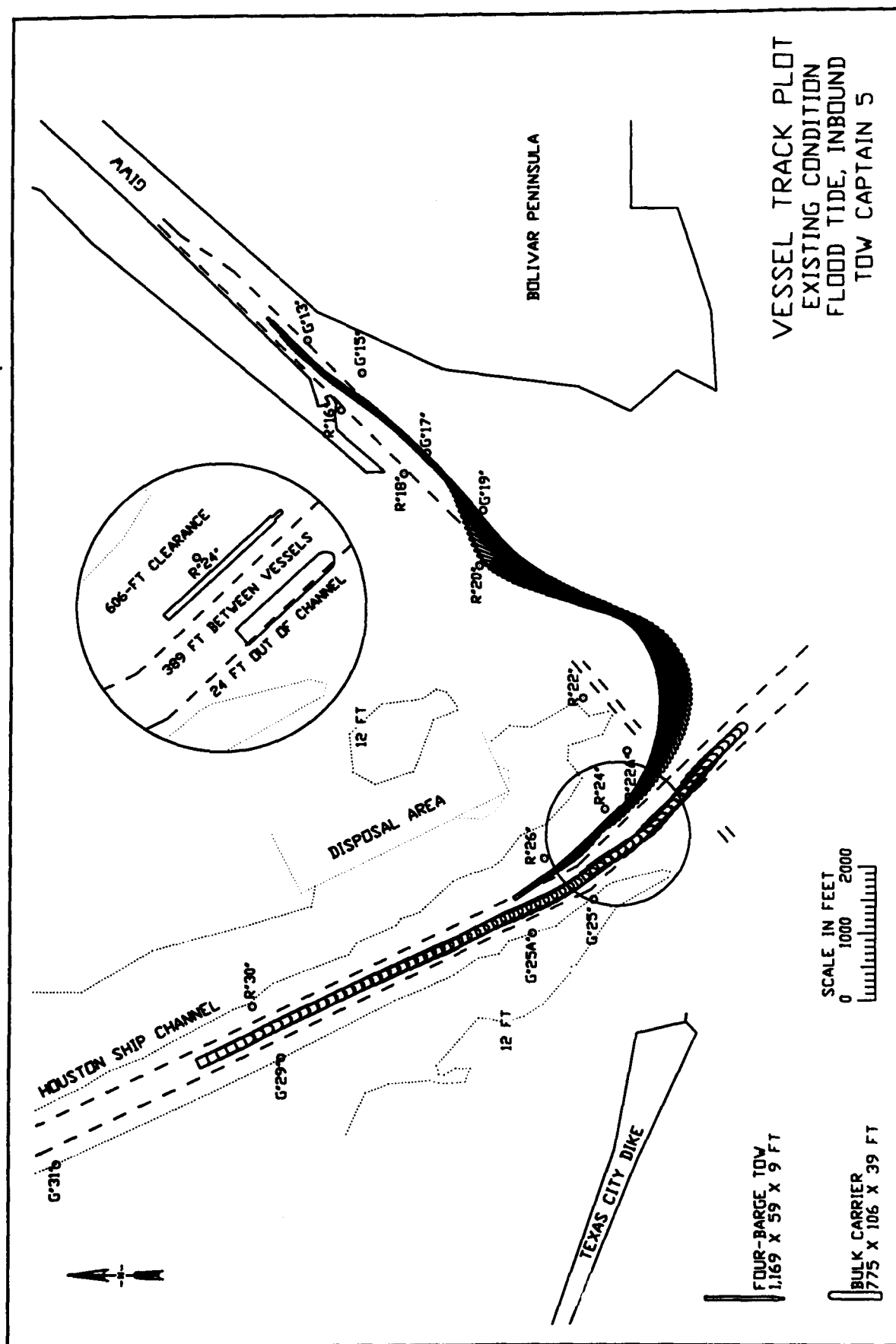
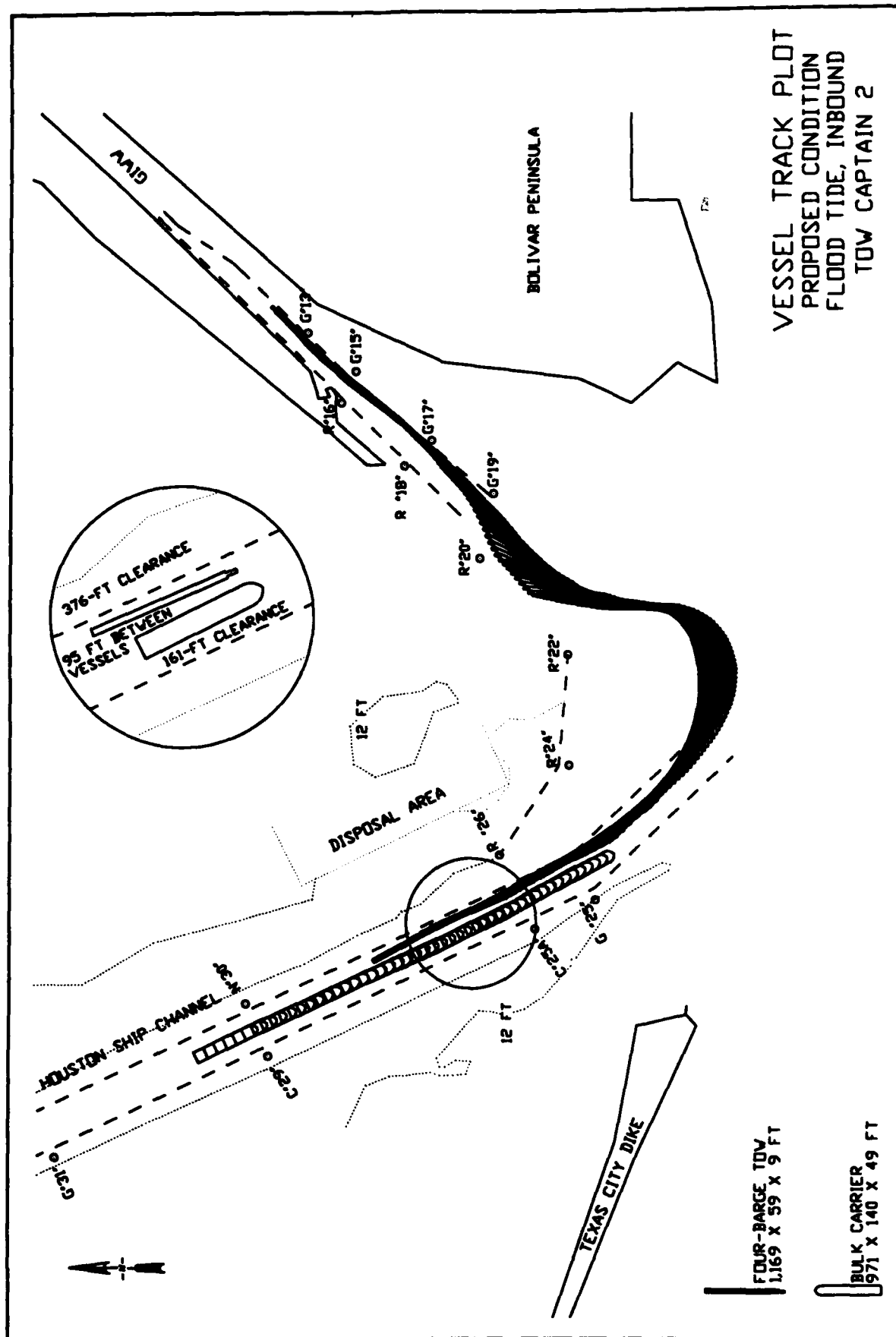


Plate 4





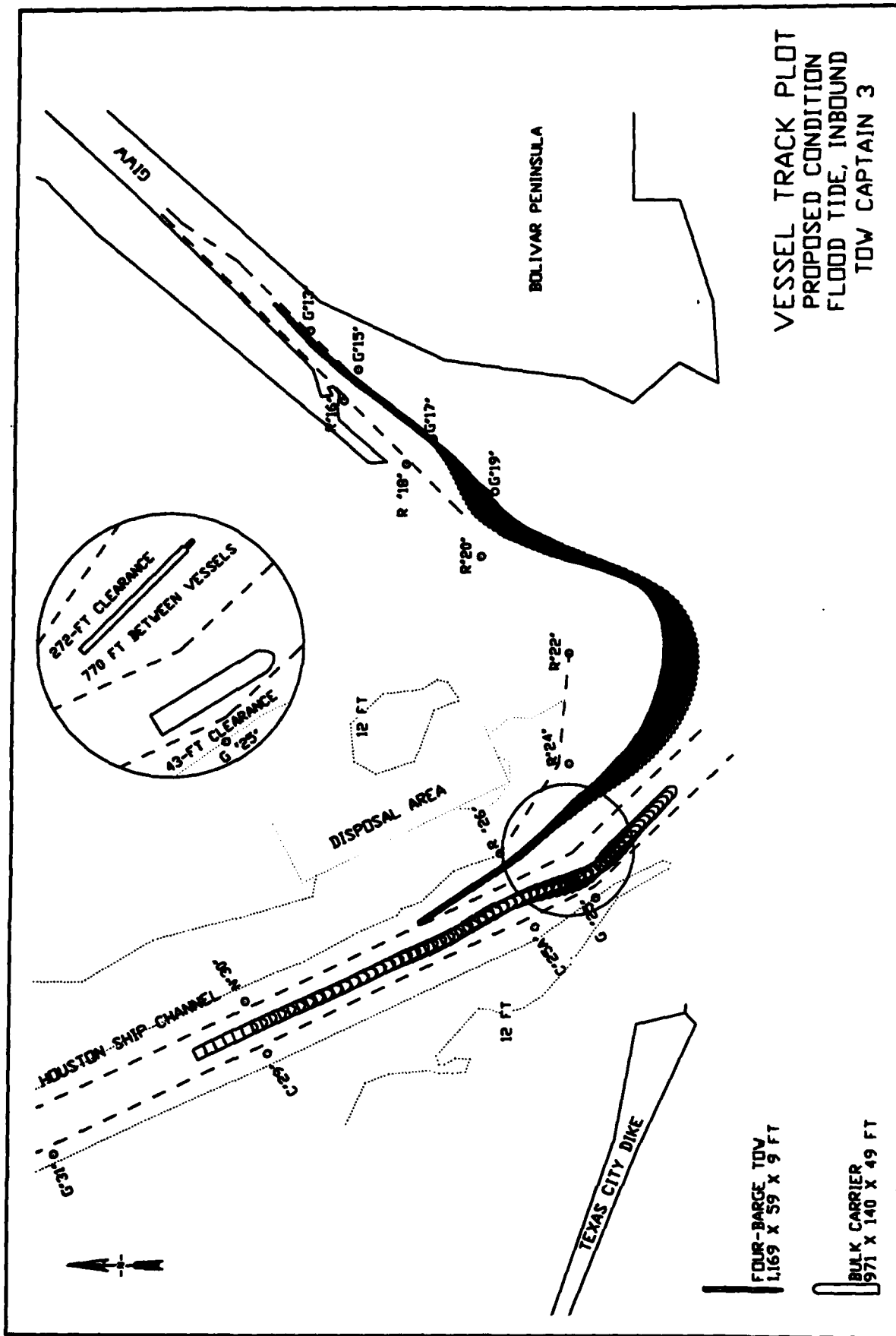


Plate 8

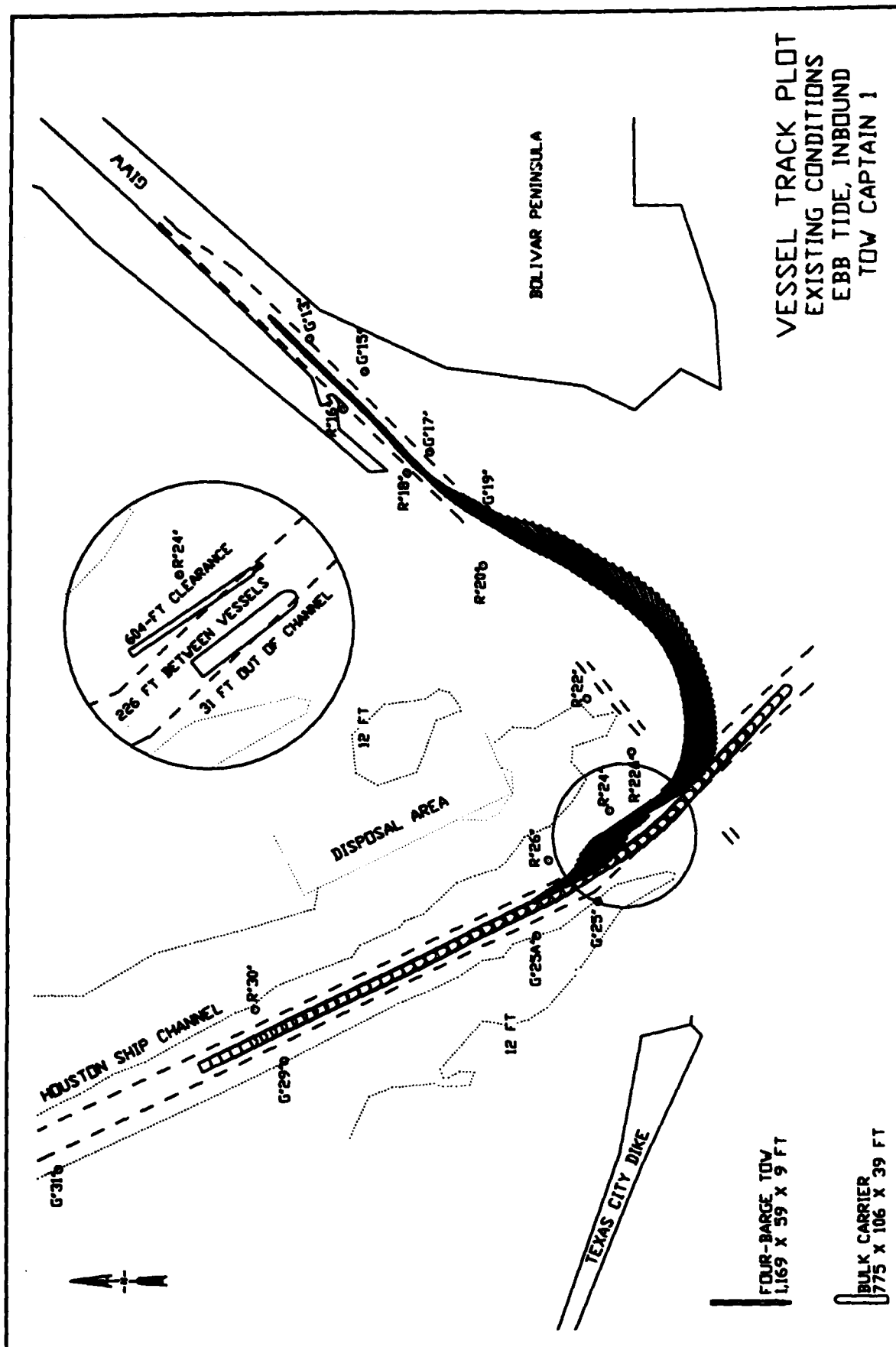


Plate 12

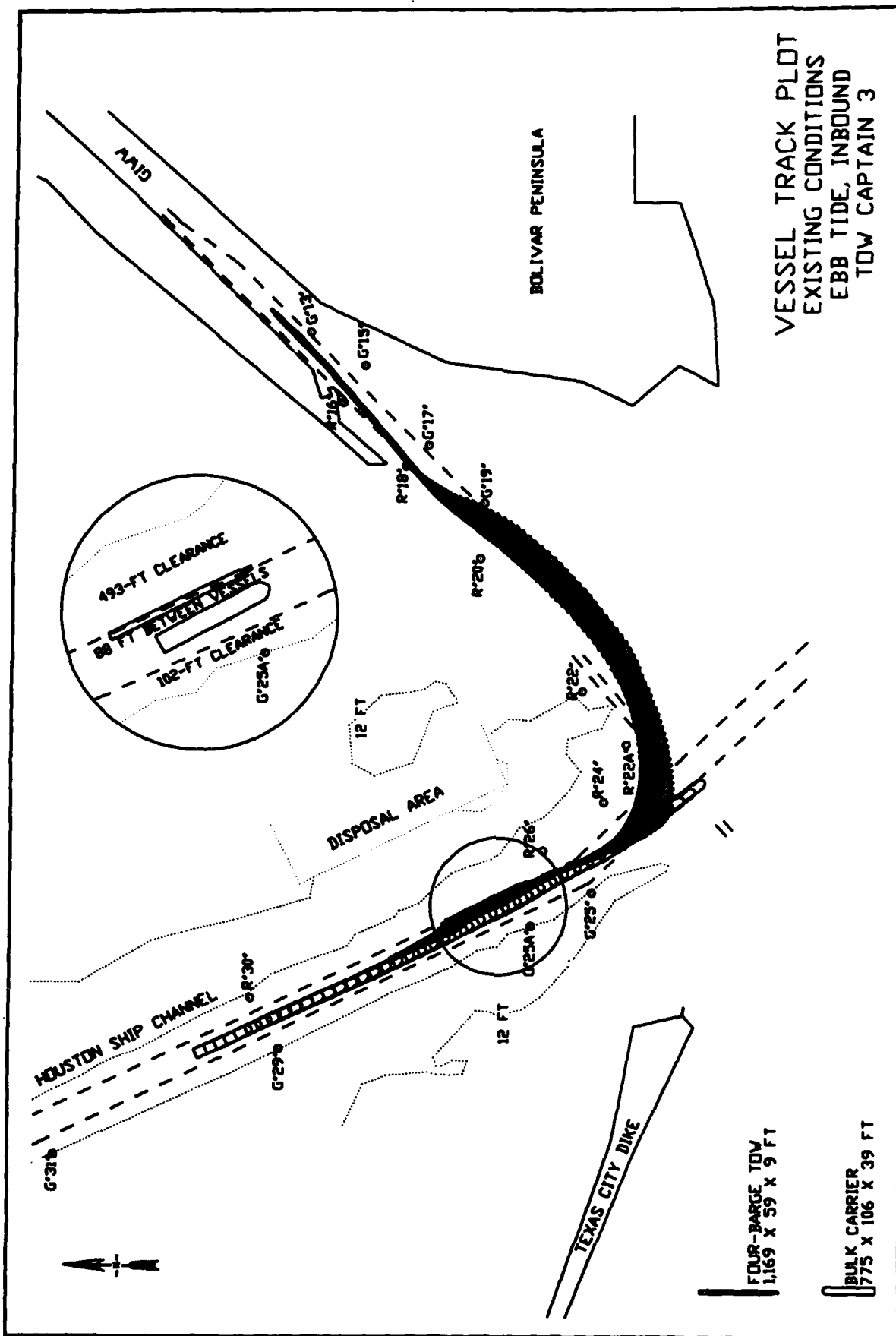
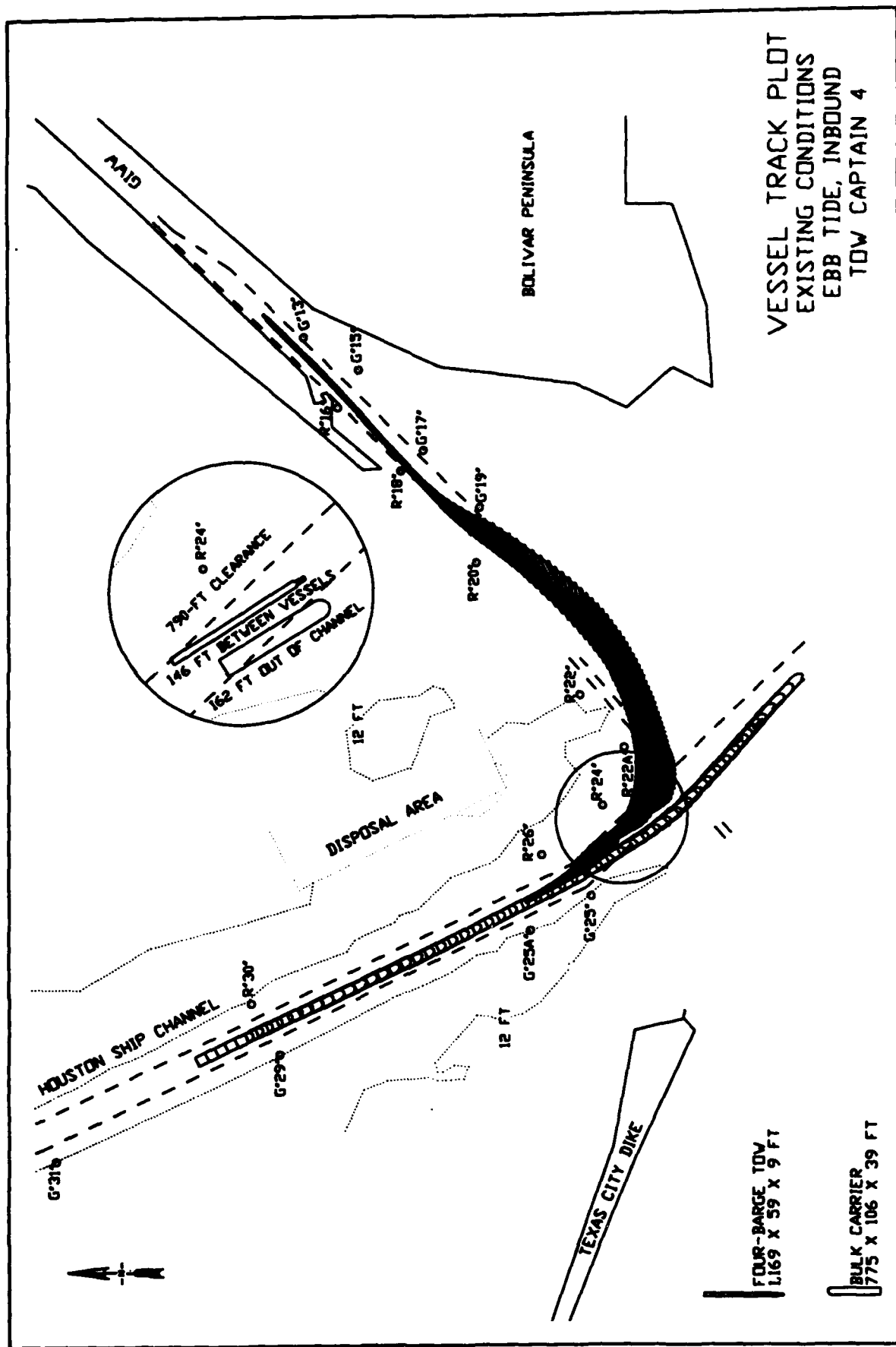


Plate 14



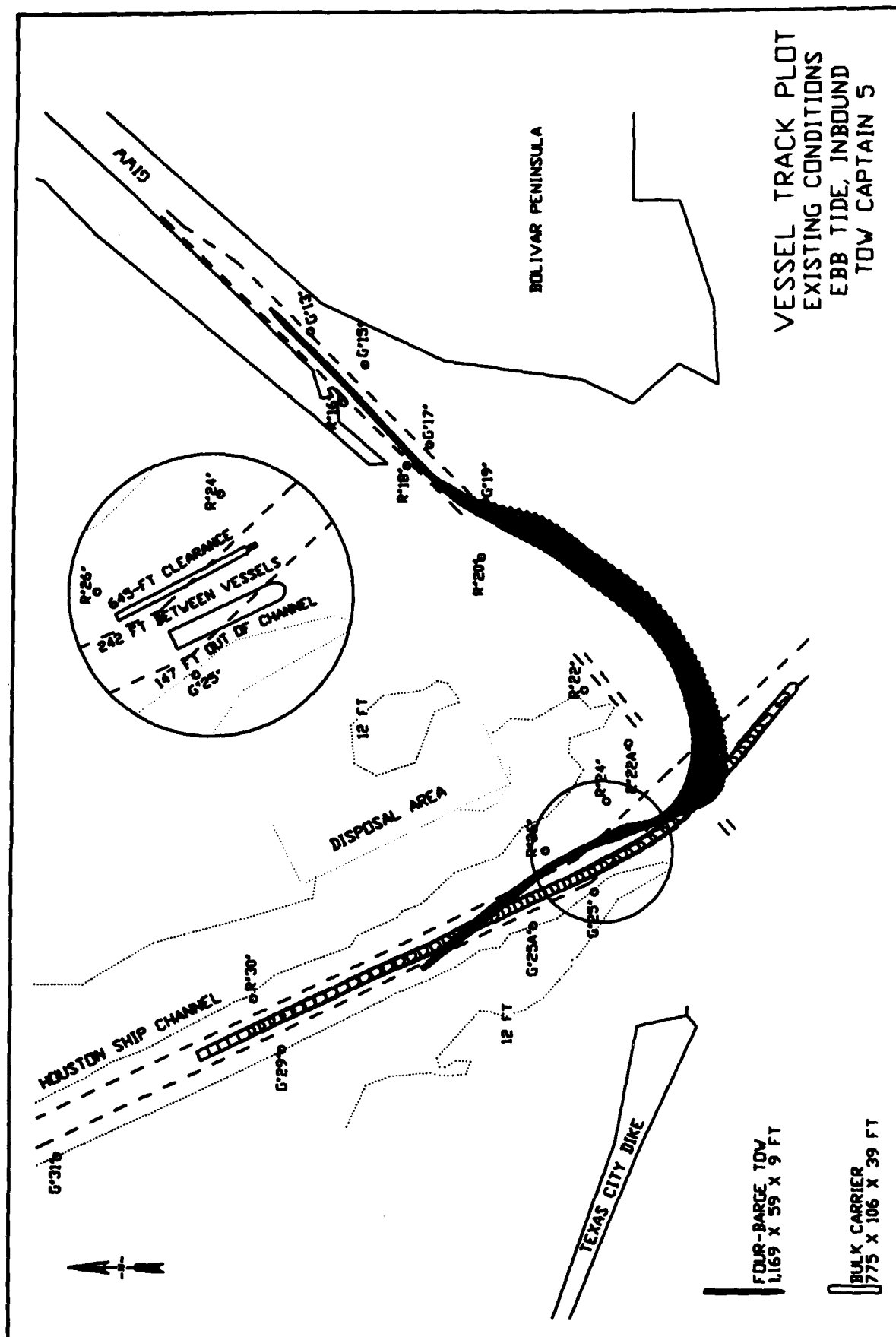
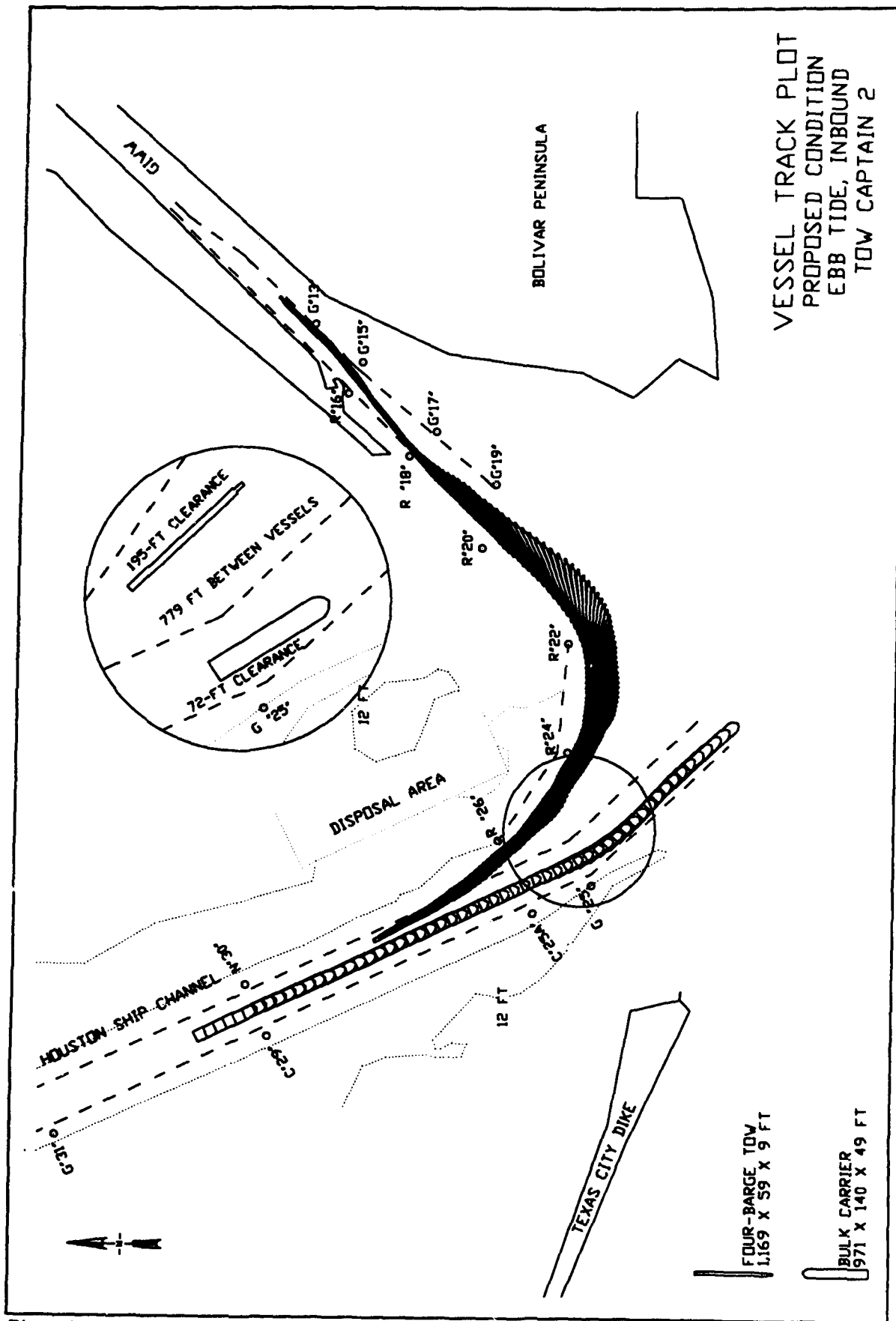
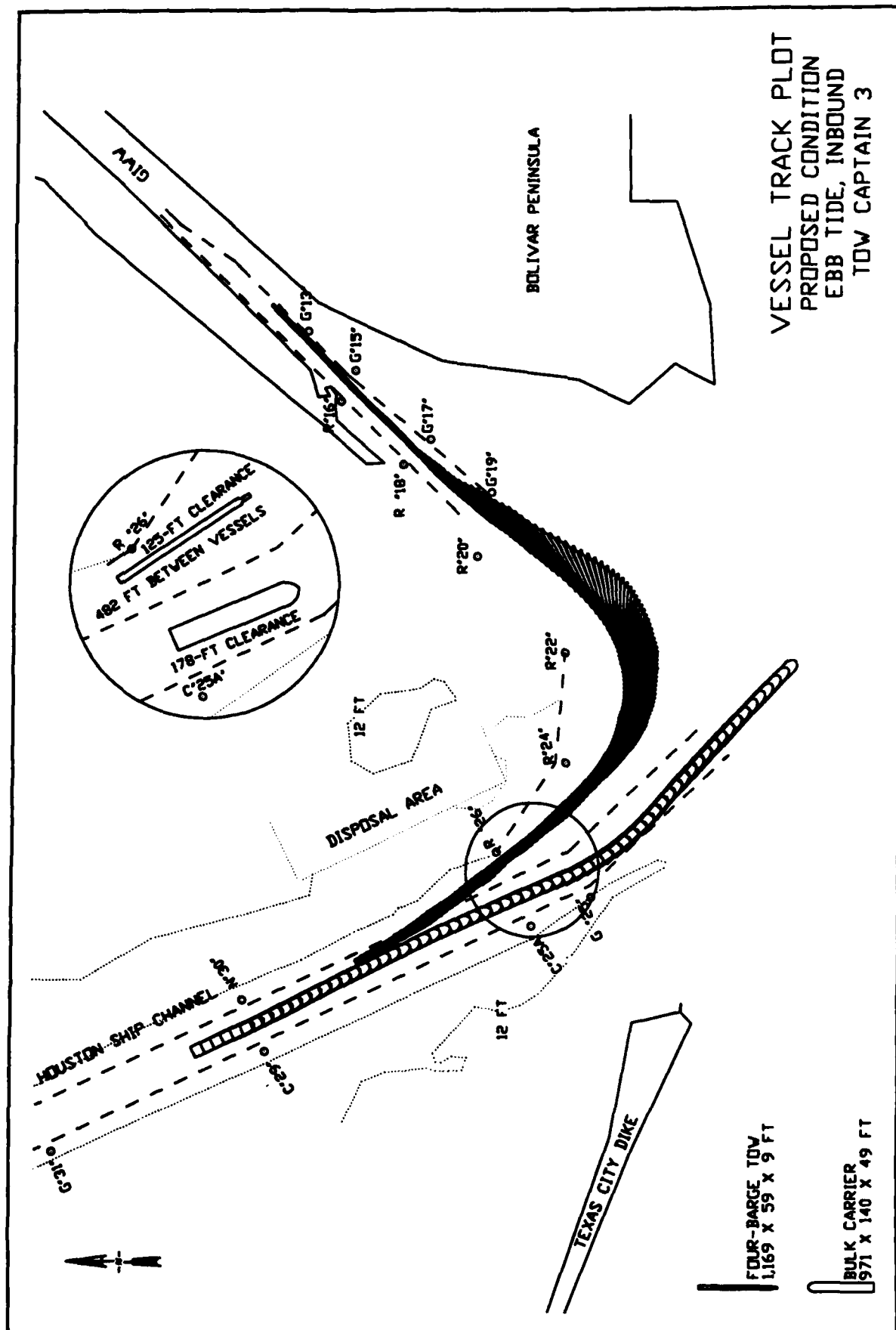
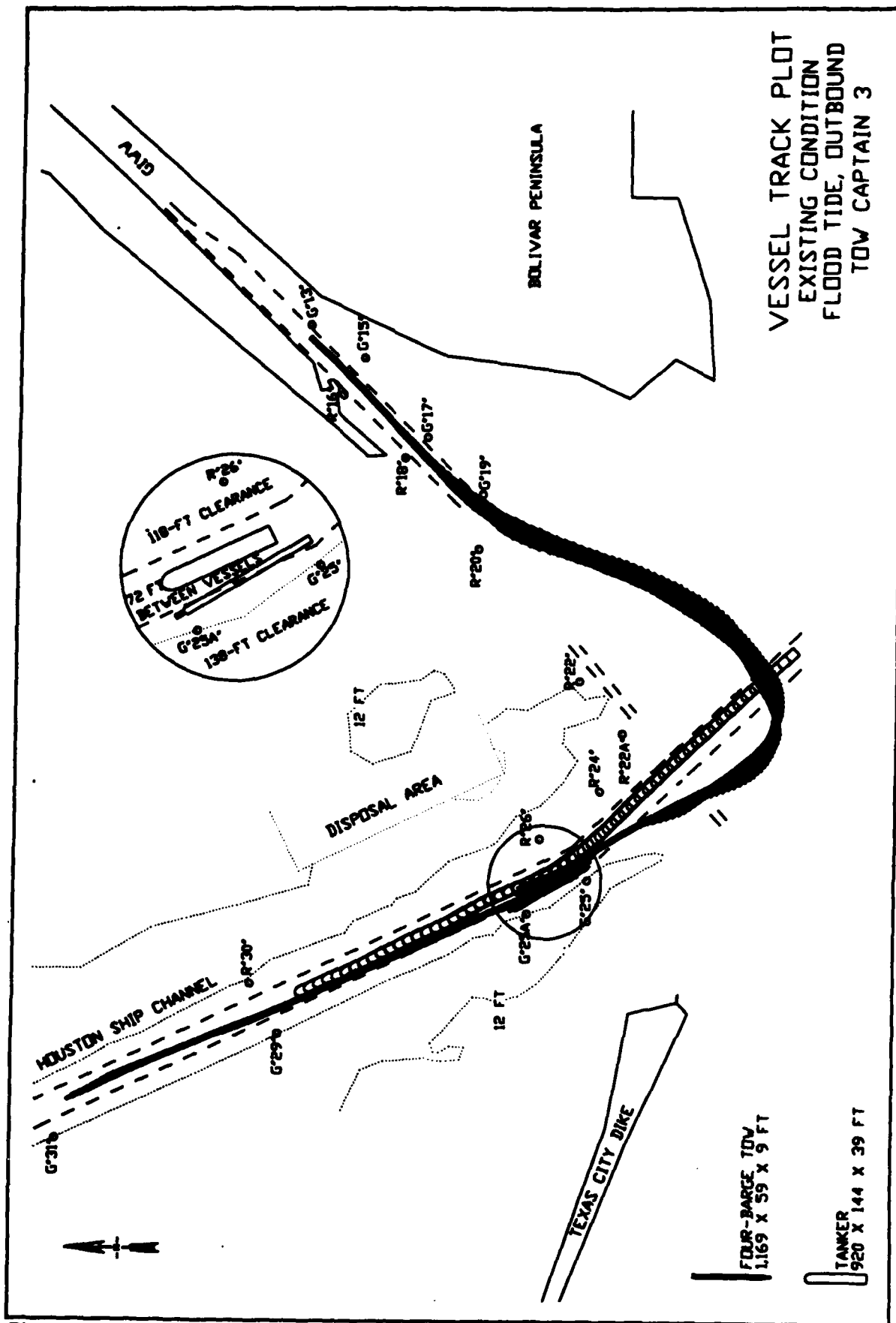


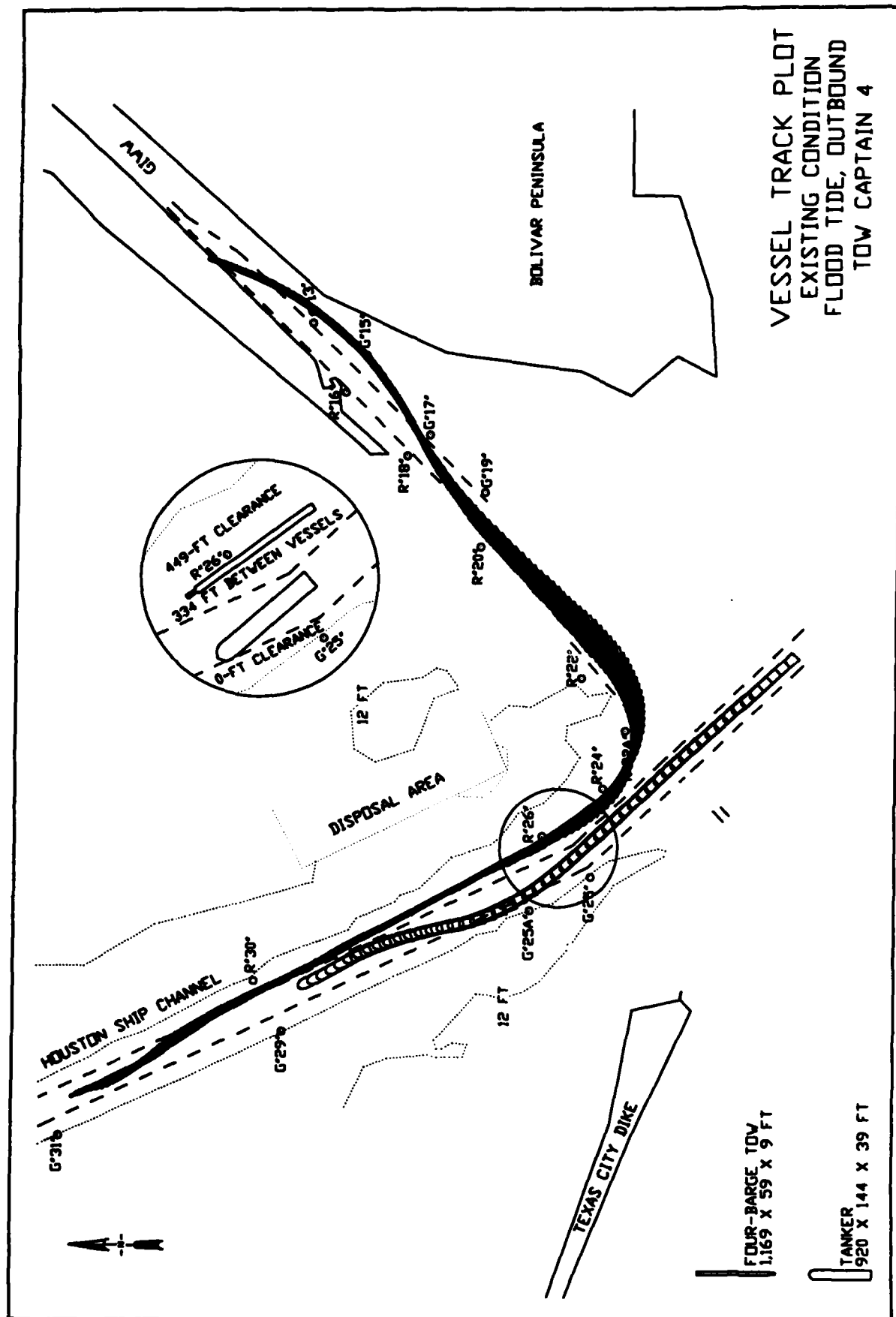
Plate 16











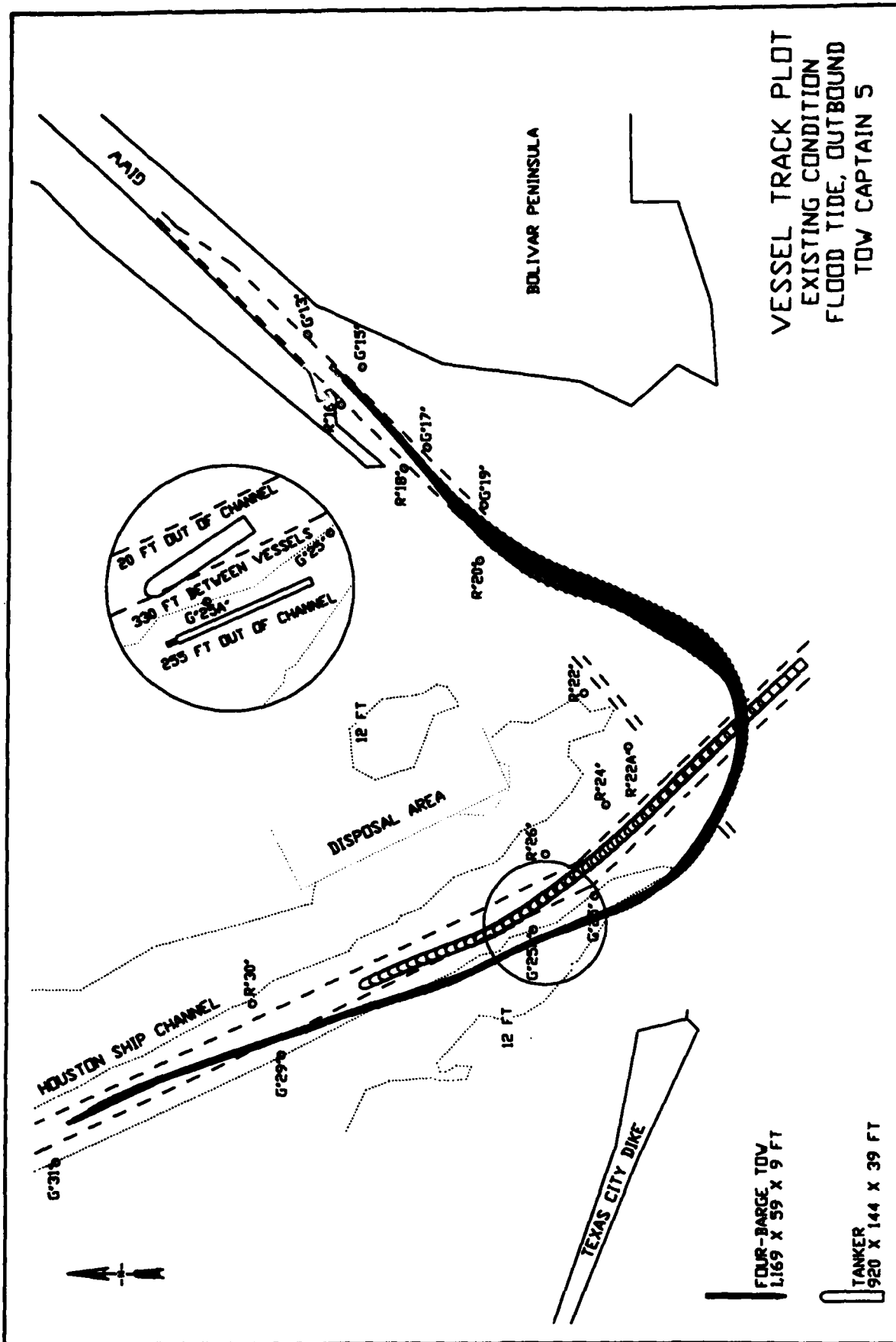
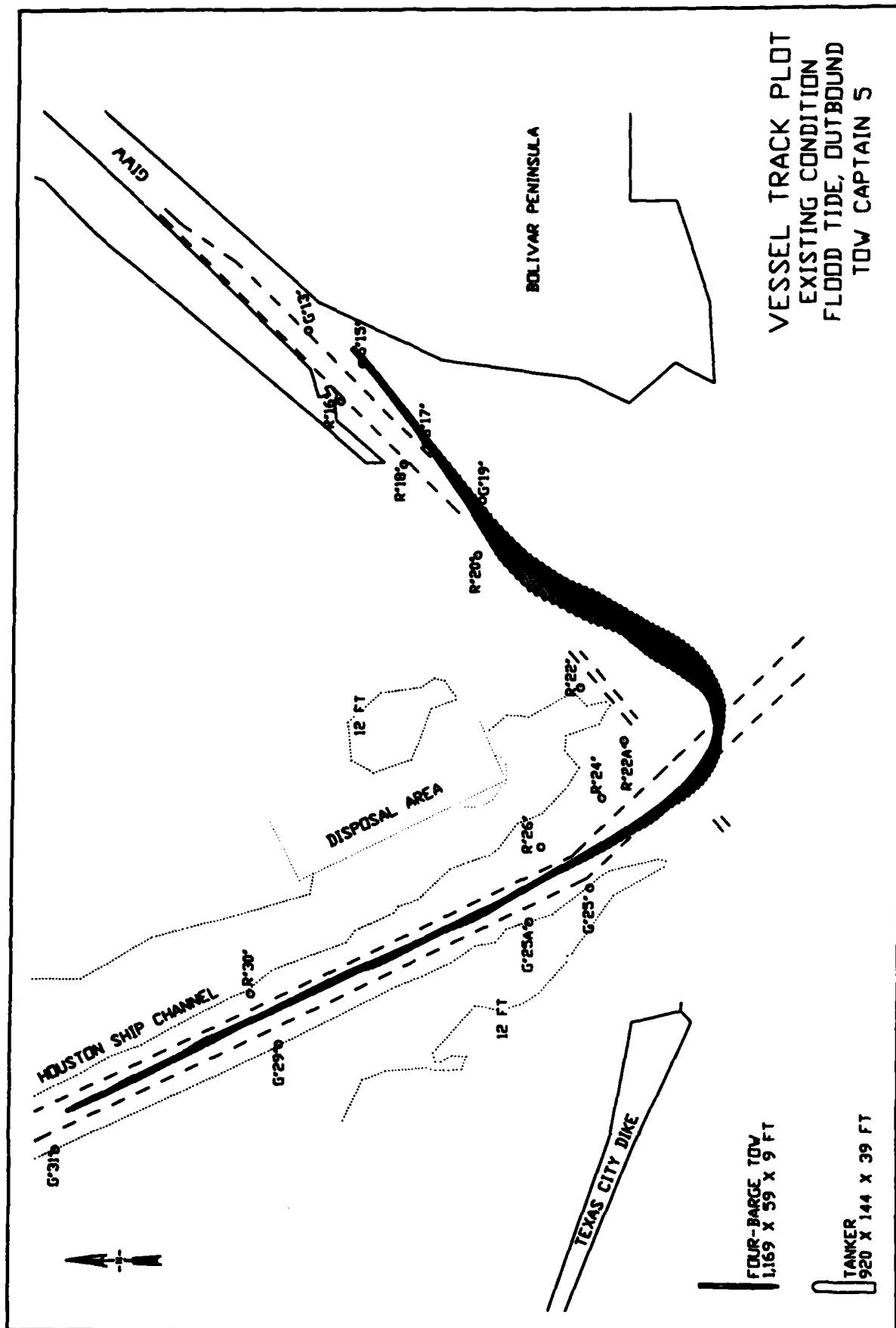
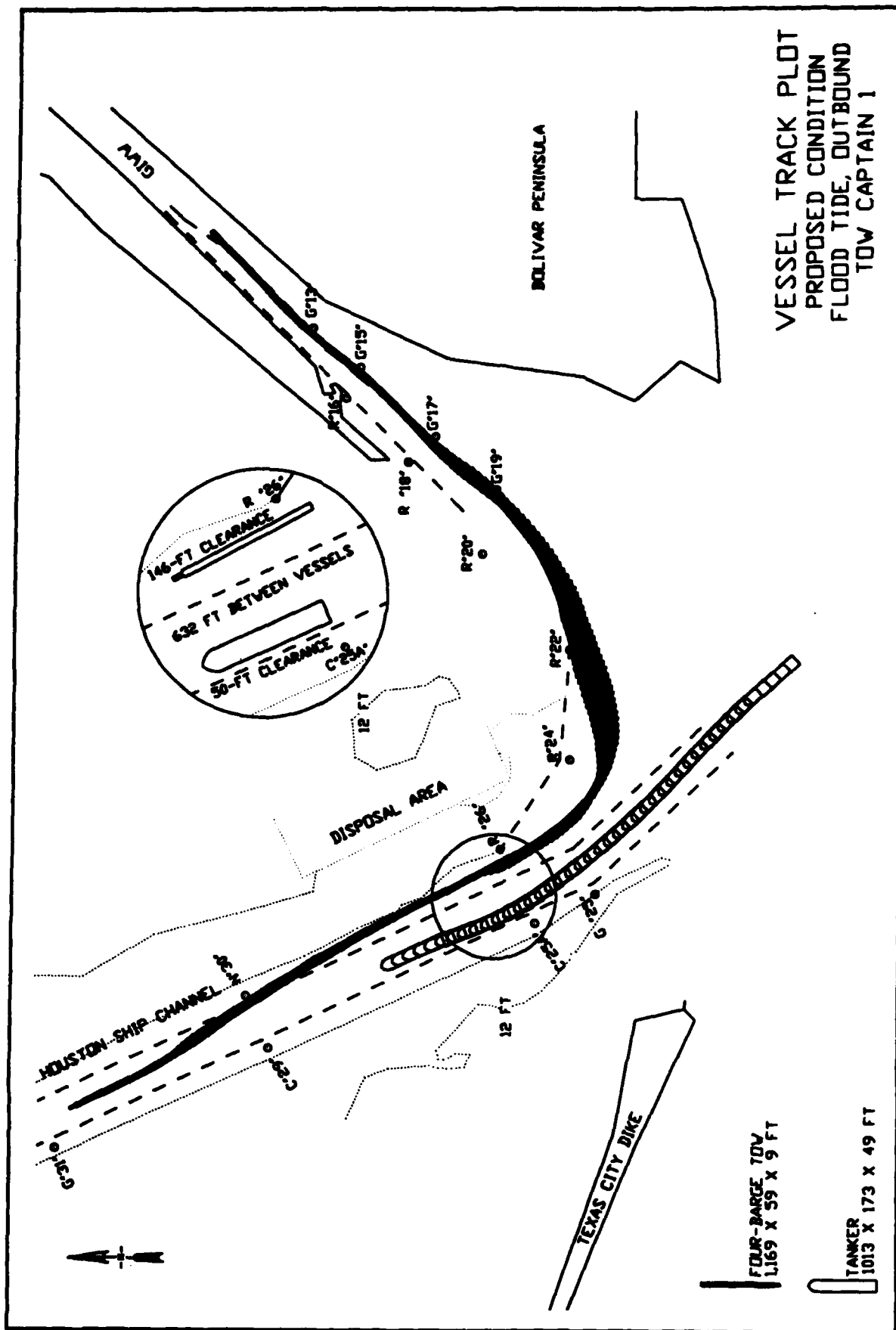
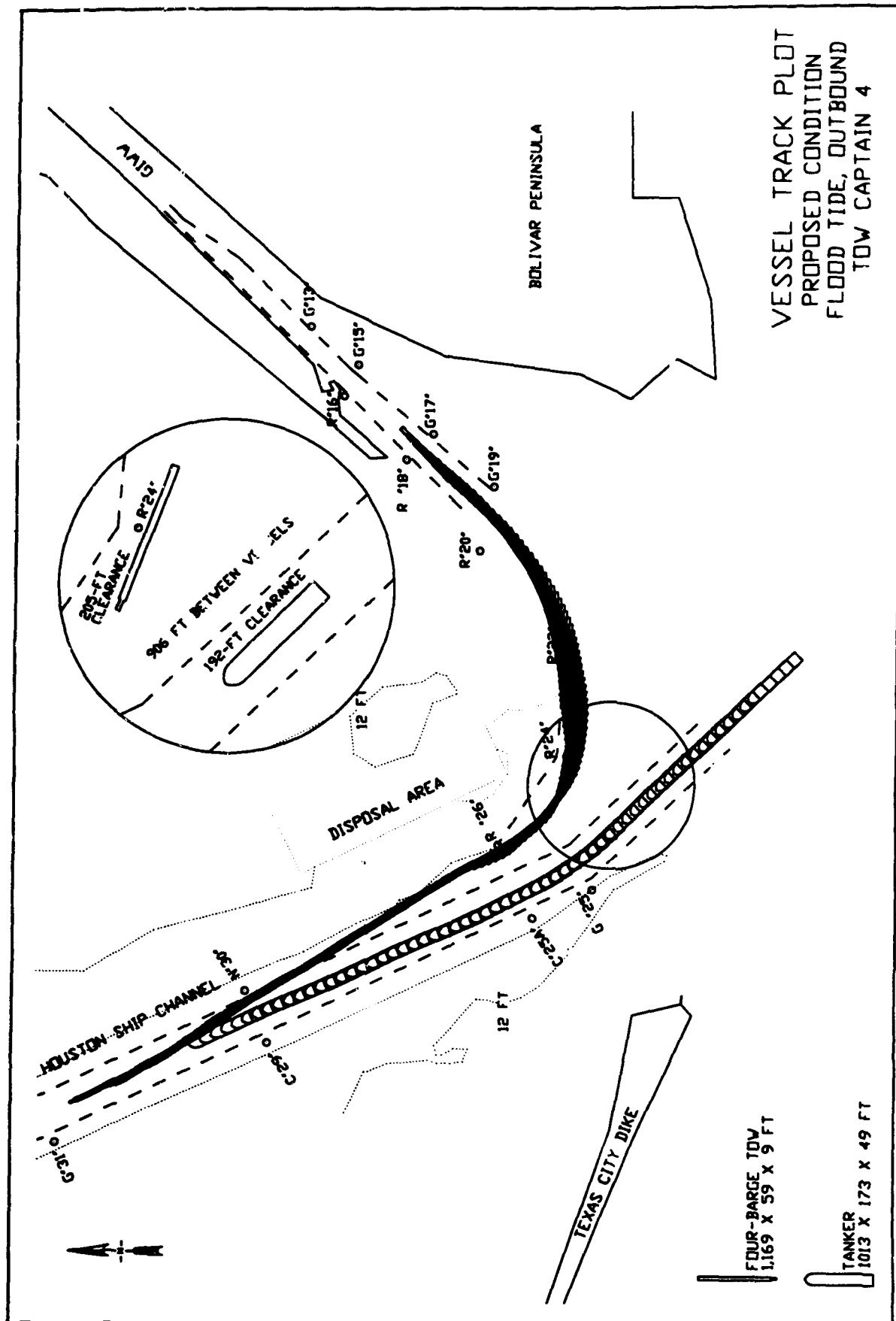


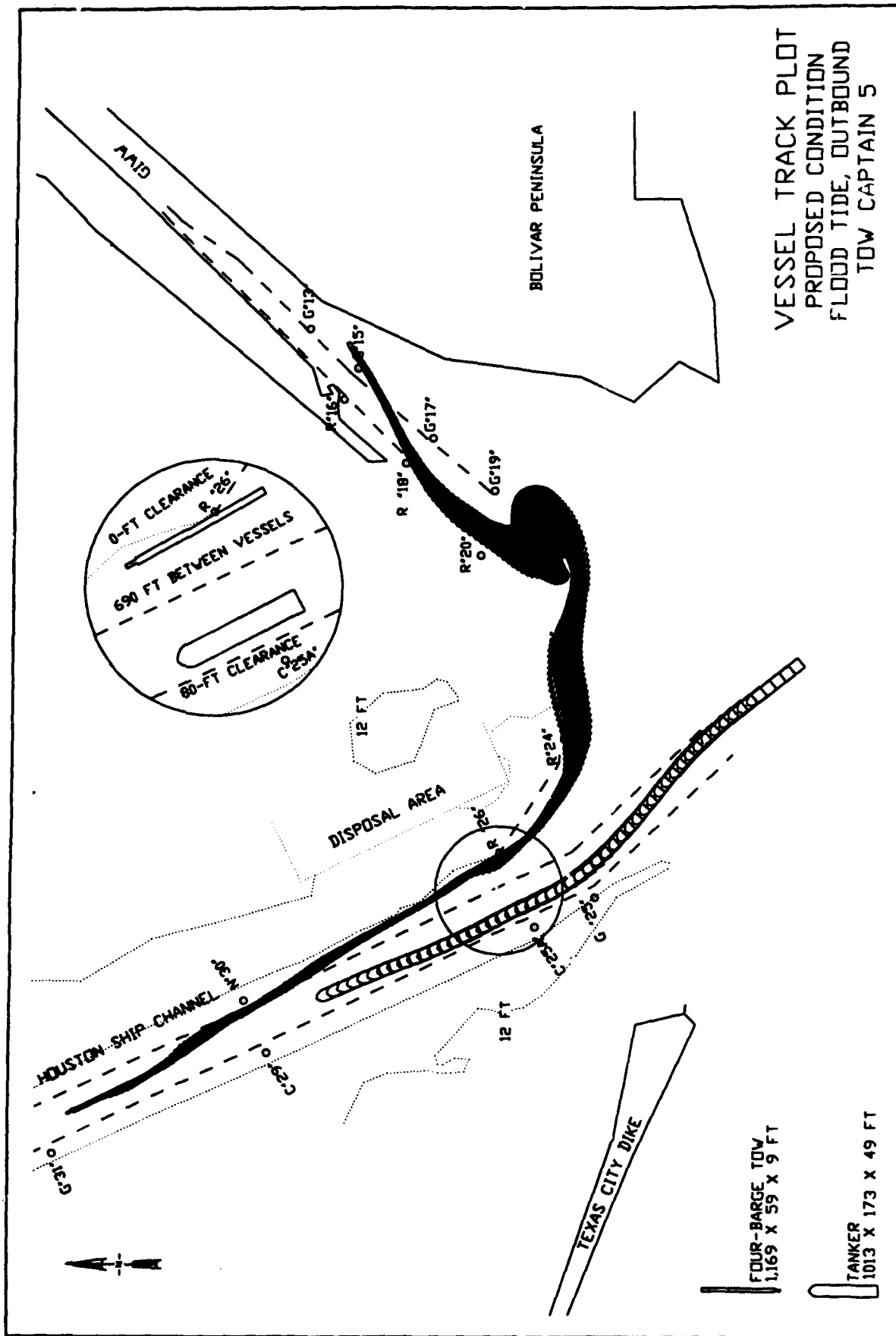
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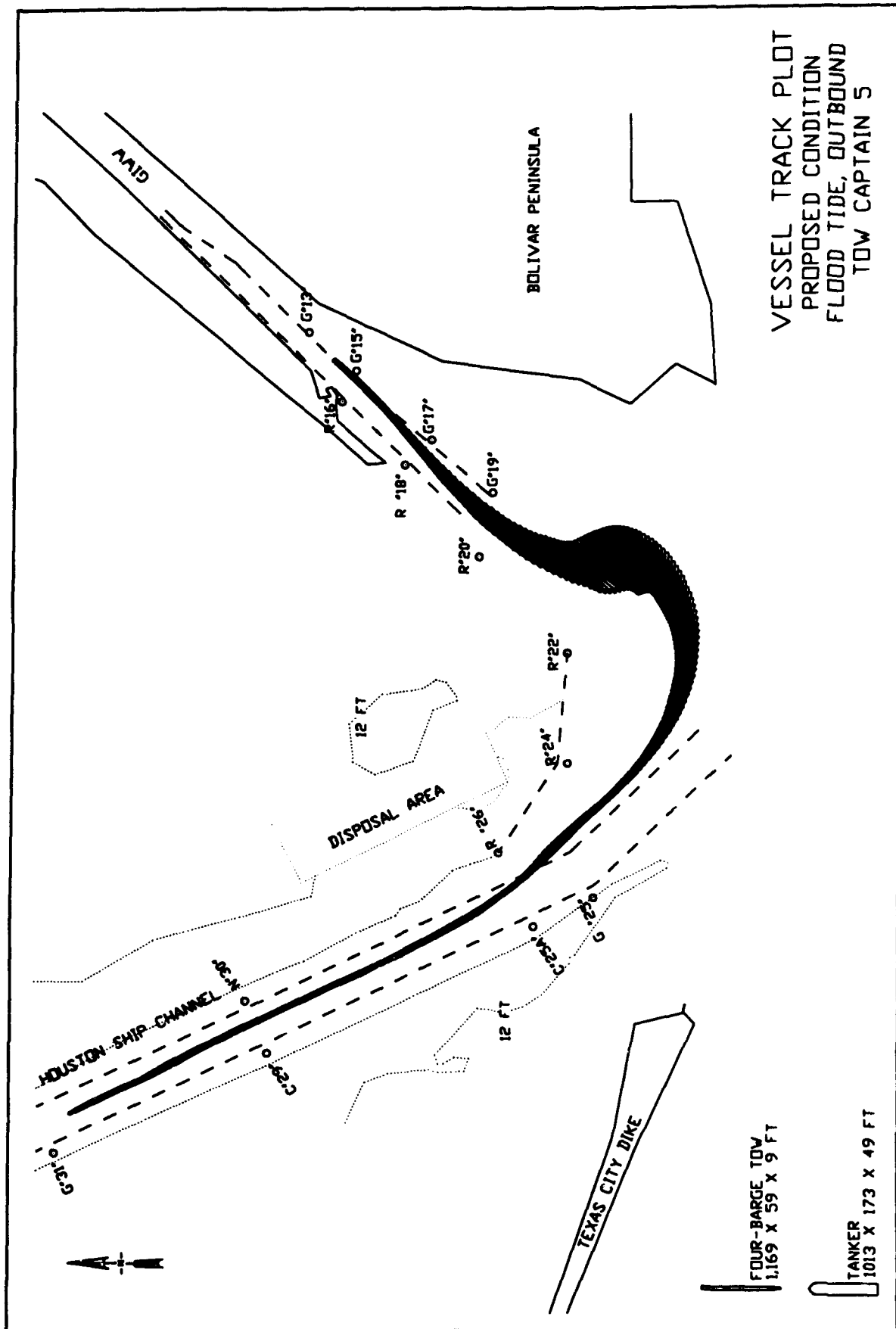














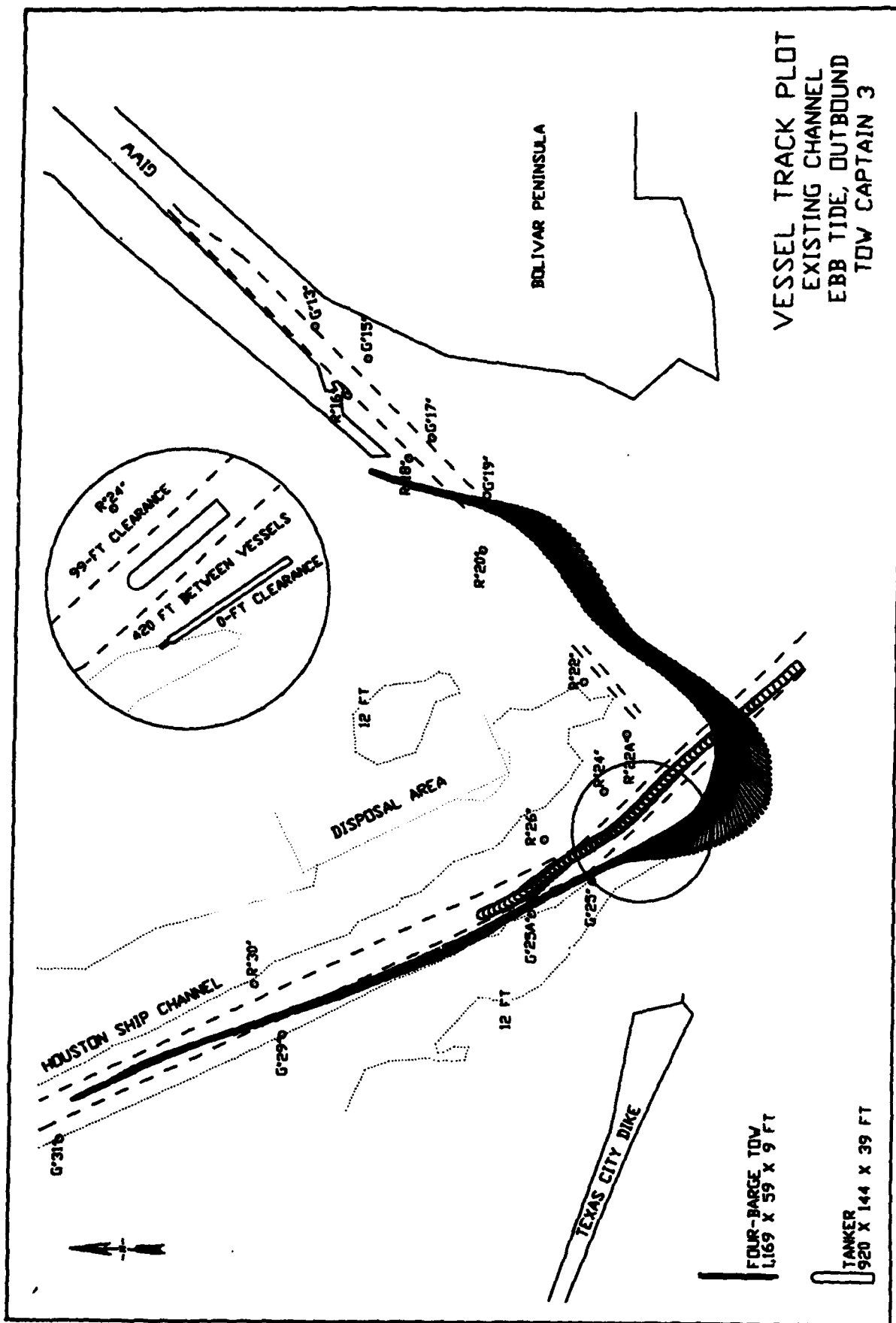
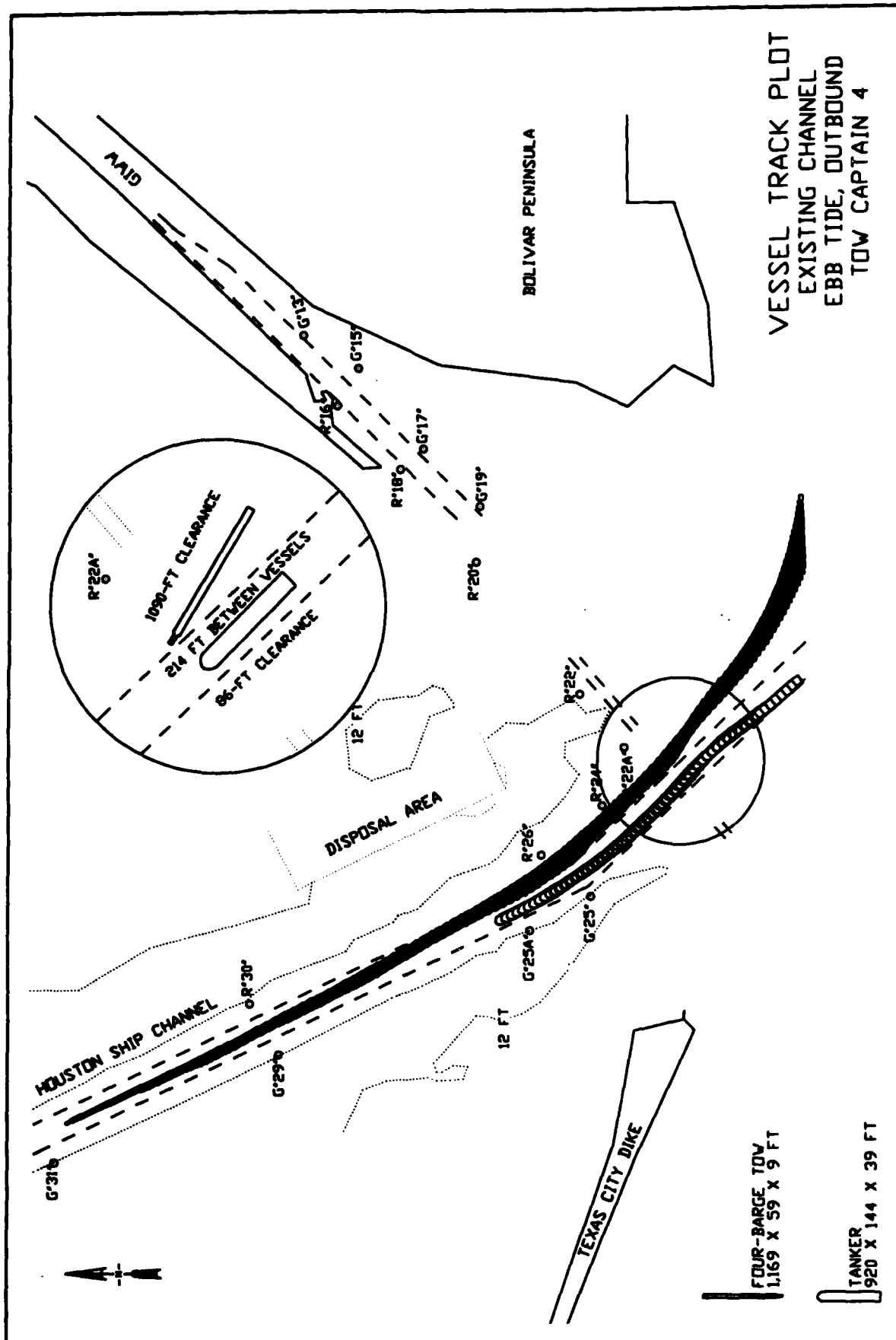
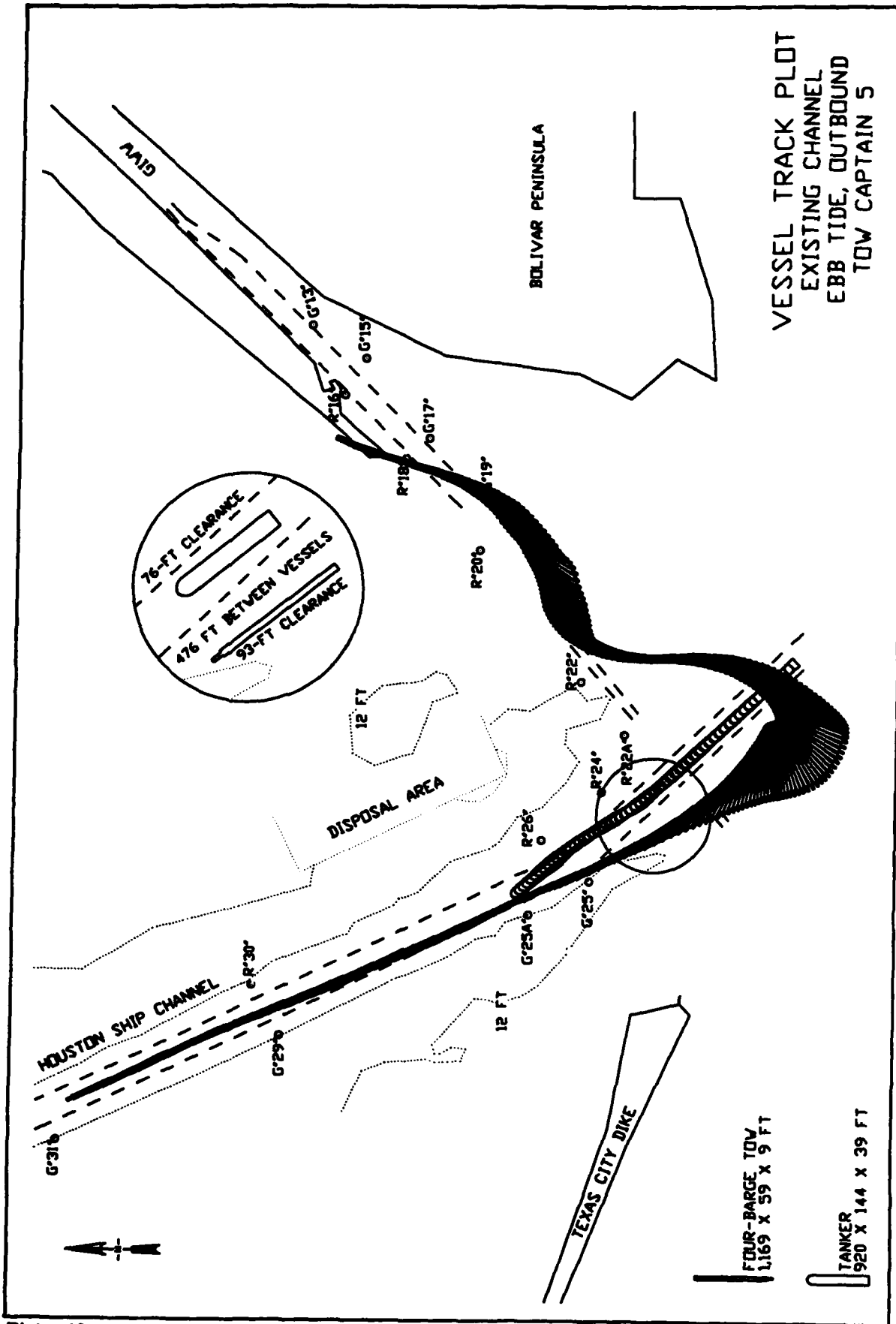
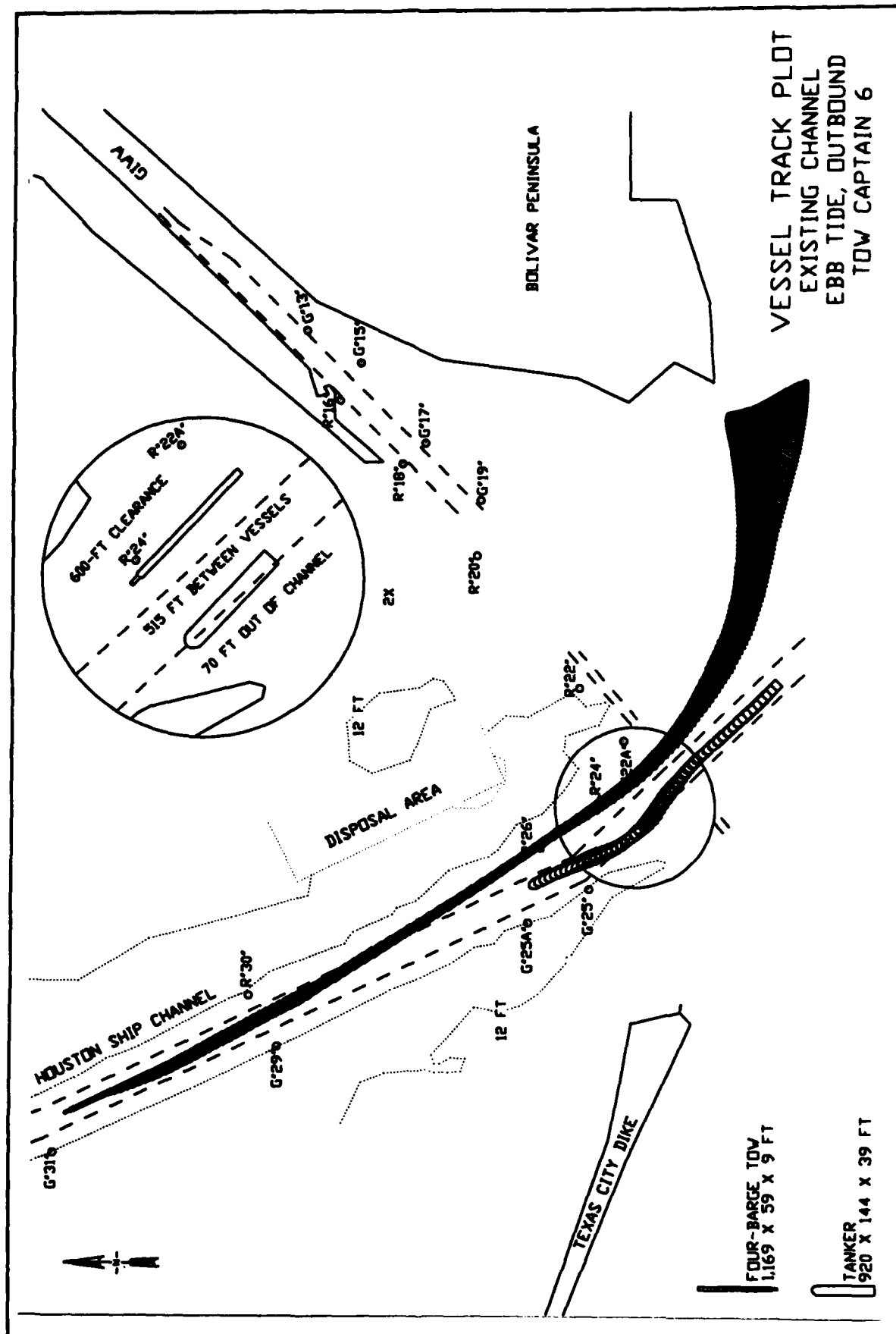
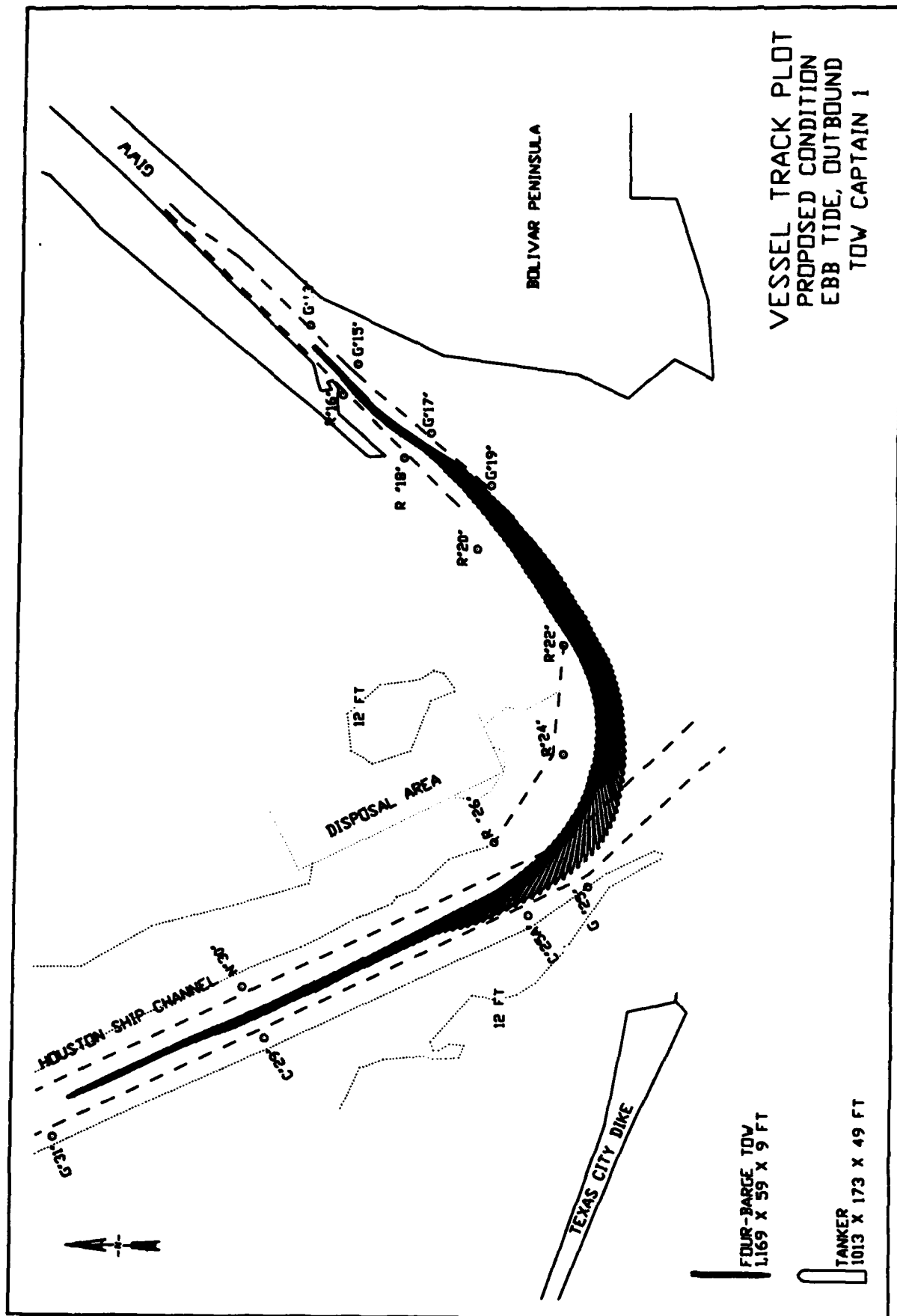


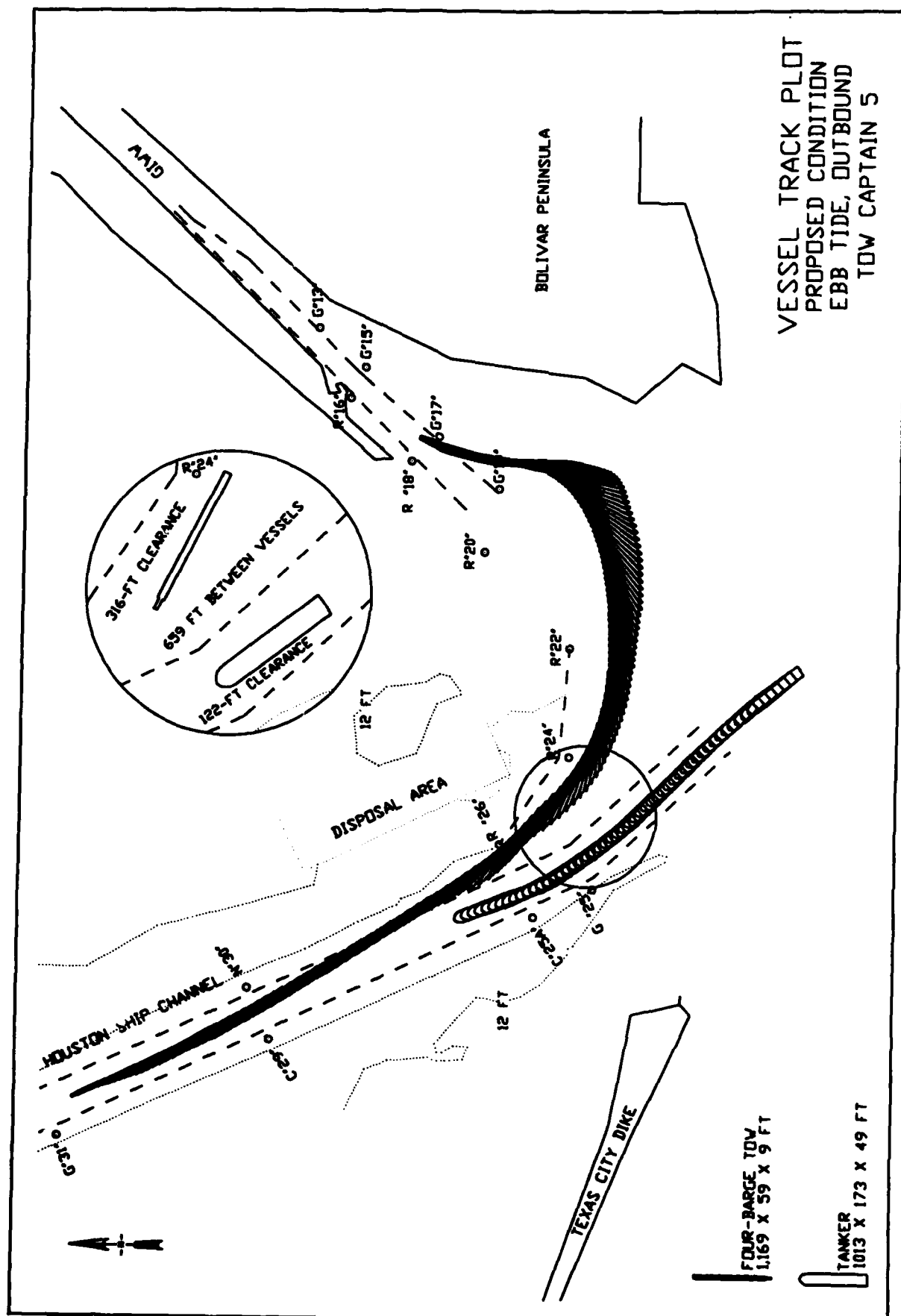
Plate 38











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